

**TECHNICAL REPORT
NATICK/TR-15/021**



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DEVELOPMENT OF A SPECTRA FABRIC PASGT- TYPE PERSONNEL HELMET

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U.S. Army Natick Soldier Research, Development and Engineering Center
Natick, Massachusetts 01760-5000**

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14. ABSTRACT This report documents an effort that took place from October 1987 to September 1989 by AlliedSignal Inc. to develop a resin prepreg system compatible with Spectra® fabric, and to fabricate helmets which have equal ballistic protection to the current Personnel Armor System, Ground Troop (PASGT) helmet, but with at least 1/3 weight reduction utilizing Spectra® woven fabric prepreg. During the performance period, Allied evaluated various resin systems and identified suitable resin systems for Spectra fabrics, and in January 1989 developed a new resin system (polyurethane/vinylester). This resin system was used by the U.S. Army to evaluate Spectra 900 shells. 175 Spectra helmets were produced for Phase II, Task B. Ballistic evaluation with various projectiles showed that at around 1/3 of the weight of the current PASGT helmet, Spectra® fabric composites showed significantly improved protection except against 2-grain Right Circular Cylinder (RCC) projectile where the performance is slightly lower than current PASGT helmet																																		
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**DEVELOPMENT OF A SPECTRA
FABRIC PASGT - TYPE
PERSONNEL HELMET**

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SECTION 1.0 SUMMARY

AlliedSignal Inc. was awarded contract DAAK60-87-C-0089/D by the U.S. Army Natick Research, Development and Engineering Center for the development of a Spectra fabric PASGT-type personnel helmet. The program was structured with two development phases: Phase I for resin development and Phase II for optimization and manufacture of 175 Spectra helmets with the matrix system selected in Phase I. The work in Phase II was further subdivided into two tasks: Task A for optimization of resin composition and processing and Task B for manufacturing 175 helmets.

At the completion of Phase I, AlliedSignal recommended three matrix-resins (vinylester, melamine/polyvinyl acetate and polyurethane) for the fabrication of Spectra helmets. These three resin systems meet all of the requirements for a military PASGT type helmet matrix resin and exhibited the required environmental resistance for military use. This resin system could be used with conventional prepregging equipment with the Spectra fabric, yielding high quality Spectra fabric prepregs. Moreover, the processibility of these prepregs to fabricate helmets required no special equipment.

Based on the results obtained from the Phase I of the program, the U.S. Army Natick Research, Development and Engineering Center decided to select two matrix resins (vinylester and phenolic/polyvinyl butyral) for resin process optimization and construction of Spectra 1000 helmets during Phase II, Task A. Spectra 1000 fabric of Style 952, 34x34 plain weave, was used as the basic construction material.

In Phase II-Task A twenty six (26) Spectra shells with a vinylester matrix were delivered to the U.S. Army for ballistic testing against various fragment simulating projectiles (2,4,17 and 64 grains), transient deformation and tumble testing for paint and rubber edge adhesion. Ballistic performance (V_{50}) was measured at 2,136 fps with .22 caliber FSPs for Spectra shells weighing 2.5 pounds. However, delamination and excessive transient deformation was observed. All of the Spectra shells were molded using the basic fabric prepreg pattern of 6 lobes. The 6 lobe pattern had the best overall performance with respect to better conformity to the mold configuration and higher total specific energy absorption. Additional crown patches were also used to improve local ballistic performance.

In January 1989, AlliedSignal developed a new resin system (polyurethane/vinylester) for uniaxial preregs on an internally funded program. After observing some encouraging findings, the use of the new resin was extended to Spectra 900 fabric (Style 903). The U.S. Army agreed to evaluate Spectra 900 shells with this new polyurethane/vinylester resin system.

Ballistic testing by the Army in Task IIA indicated that a 2.3 pound Spectra 900 shell made from the polyurethane/vinylester resin had an overall average V_{50} of 2,271 feet per second. The transient deformation, measured against 44 grain and 64 grain fragment simulating projectiles, was 1.5 and 2.42 inches for Spectra shells. The corresponding values for aramid shells was 1.55 inch and 2.25 inches. Spectra 900 shells made from the polyurethane/vinylester resin delaminated much less than shells with vinylester phenolic/PV B during ballistic testing. Tumble tests conducted by the Army also showed that paint adhesion was acceptable and no rubber edge separation was observed.

The Army subsequently agreed that polyurethane/vinylester was the best resin for the Spectra helmet shells and Phase II Task A was therefore, completed. The Army approved the continuation of Phase II, Task B, and 175 Spectra helmets were produced at Sioux Manufacturing Co., Fort Totten, North Dakota using commercial equipment.

SECTION 2.0

INTRODUCTION

This program entitled "Development of a Spectra Fabric PASGT-type Personnel Helmet" was initiated in October 1987 under Contract DAAK60-87-C-0089/D with the U.S. Army Natick Research, Development and Engineering Center. Phase I of this program was completed on September 30, 1988. Phase II - Task A was completed on June 22, 1989. Phase II - Task B, the final phase of this contract, was completed on September 22, 1989.

The major achievement in Phase I of the program was the development and selection of the three resin systems which could be made into Spectra 1000 fabric prepreg to produce laminates capable of providing improved ballistic protection, at lighter weight, than existing aramid composites for military PASGT helmets. The goal in Phase I was to develop resin systems compatible with Spectra 1000 fabric which would meet the specified ballistic performance requirements with an areal density of 25.5 ounces per square foot or equivalent to a 2.1 pound shell weight for a medium size PASGT type helmet.

Various classes of resins, both thermoset and thermoplastic, were investigated with regard to their suitability for use as matrix materials with the Spectra fabric. The identified most promising resins were evaluated and modifications were made to improve their ballistic performance and mechanical properties. This report describes the results of the resin evaluation and developmental work performed during Phase I. Specifically, this report contains: the results of resin screening experiments the ballistic performance of shells with various resins; environmental effects on ballistic performance; shelf life data of the thermoset resins; and other results.

After completion of Phase I, Phase II - Task A effort focused on process optimization to produce Spectra helmet shells produced using two resin systems selected jointly by the U. S. Army Natick Research, Development and Engineering and the U. S. Army Materials Technology Laboratory (MTL). Spectra helmet shells were fabricated at AlliedSignal and tested by the U. S. Army for ballistic performance, transient deformation, delamination, paint and rubber edge adhesion.

In January 1989, AlliedSignal Inc. discovered a new resin system, to be used with uniaxial preregs, which appeared to be an excellent candidate material for this program. AlliedSignal informed the U.S. Army Natick Research, Development and Engineering Center (Natick) of this new resin system and Natick concurred with the AlliedSignal findings that the helmets made from this new resin should be evaluated.

SECTION 3.0

SCREENING OF MATRIX RESINS

The main objective of the screening process used in this program was to facilitate the selection of the best performing resin systems. A wide variety of candidate resins, both thermoplastic and thermoset, were investigated to select the best matrix resin which would be used with the Spectra 1000 fabric. The material selected would be required to provide ballistic performance and structural integrity equal to currently fielded PASGT type helmets.

AlliedSignal decided on a number of key criteria for the selection of this resin. These criteria included that the resin system selected must be processable or curable at a temperature lower than 120°C and that it must have a shelf life of at least ninety days at room temperature. In addition to these requirements, this matrix resin must have sufficient interfacial adhesion to maintain the structural integrity of a helmet with minimum delamination during use by troops in military operations. The resin selected must also be compatible with conventional prepregging equipment to impregnate this resin on the Spectra fabric, yielding high quality Spectra fabric prepregs. Finally, the processability of the prepreg to fabric must require no special equipment.

Through a thorough and detailed screening process conducted in the Phase I of the program, AlliedSignal recommended three resin systems: (A) polyurethane, a thermoplastic, (B) vinyl ester, a thermoset; and (C) a 50/50 blend of polyvinyl acetate and melamine-formaldehyde, a interpenetrating network polymer system of thermoplastics and thermosets. While the work was in progress, AlliedSignal Research personnel, working independently on another internally funded development program, determined that the addition of vinyl ester resin into polyurethane had a profound improvement on vinyl ester resin as a matrix resin for Spectra uniaxial prepregs. Therefore, AlliedSignal expanded this evaluation to polyurethane/vinyl ester as the fourth matrix system to be evaluated for use with fabric prepregs. After examining a series of positive results including ballistic performance testing and adhesion tests, the US Army authorized this resin system for the manufacture of helmet shells in Phase II Task B of the program.

All four resins met all of the criteria for a matrix resin and exhibited the required environmental resistance required of military helmets. In addition, conventional prepregging equipment could be used to impregnate these resins on Spectra fabric, yielding high quality Spectra fabric prepregs. Moreover, the processability of these prepregs for fabricating helmets required no special equipment.

3.1

MATERIAL SELECTION CRITERIA

In the Phase I of the program, criteria for matrix resin selection were established to screen potential resin candidates. The main considerations in establishing the resin selection criteria were physical and mechanical properties, chemical reactivity, crystallinity (morphology), and other requirements such as environmental resistance. The key property requirements in selecting potential matrix resins were as follows:

Modulus	10,000 - 50,000 psi
Tensile Strength	1,000 - 10,000 psi
Flexural Strength	2,000 - 10,000 psi
Shelf Life	Ninety (90) days at room temperature
Molding Temperature	Less than 120
Molding Cycle	Less than 30 minutes

In addition to these criteria, a suitable resin should have adequate interfacial adhesion to maintain the structural integrity of a helmet during handling and ballistic impact. Also, an ideal matrix resin should have characteristics of both an amorphous and crystalline nature. A crystalline nature provides rigidity and structural integrity while an amorphous nature enhances the absorption of projectile kinetic energy during a ballistic impact event.

The following polymer classes were identified to have a high potential to meet the above resin selection criteria:

Phase I

- Polyurethane
- Epoxy resin
- Polyacrylic and polyacrylate
- Polyolefin
- Polyvinyl acetate and its copolymer
- Amino resins (melamine-and urea-formaldehyde)
- Vinylester

Phase II - Task A

- Vinylester
- Phenolic/poly(vinyl-butryal
- Polyurethane/vinylester, or PU/VE

The existing commercially available resins in these classes were reviewed with respect to the above resin selection criteria. The details of the evaluation were discussed in the Phase I report on this program. After all of these resins systems were evaluated, the most satisfactory candidate systems were selected for use with Spectra 1000 fabric. These systems are shown in Table 3.2-1.

3.2 CHARACTERISTICS AND PROPERTIES OF POTENTIAL RESINS

The characteristics of the potential resins listed in Table 3.2-1 are described in detail in Sections 3.2.1 through 3.2.4. The chemical reactivity and the unique nature of the resins selected are emphasized for further modifications to improve and develop the desired properties for Spectra fabric matrix resin.

Table 3.2-1 Characteristics of Potential Resins

Resin Class	Resin	Characteristics
Polyurethane (PU)	Scotchcast ® Upaco ® WX-48- Estane ®5707F-1 Dispercoll ® E-585	Curable polyurethane Curable with Upaco WX-490 Semi-crystalline Aliphatic polyurethane
Melamine-formaldehyde	Cymel ® 303	Chemical reactivity with various polymers
Vinylester (VE)	Derakane® 8084	Crosslinked with styrene or diallyl phthalate
PU-VE	Dispercoll® E-585 Derakane® 8084	Crosslinked with styrene or diallyl phthalate

3.2.1 Polyurethanes

(1) Est 5707F-1

Estane resins are thermoplastic polyurethanes manufactured by B.F. Goodrich Company, Cleveland, Ohio. Estane polyurethanes occupy a unique position,

bridging the gap between rubbery and rigid plastics. Estane 5707F-1 is a semi-crystalline polymer, and is suitable for a solution process because of its low viscosity in various solvents. Estane 5707F-1 is a polyester based polyurethane derived from 4,4'-diisocyanodiphenylmethane and polytetramethyleneadipate. The physical and mechanical properties can be controlled by changing the chemical composition of the two components. Estane 5707F-1 resin is resistant to chemicals, abrasion and tearing. It has high tensile strength and tensile modulus, and excellent low temperature flexibility. Estane 5707F-1 exhibited the best ballistic performance among the resins AlliedSignal investigated during Contract DAAL04-87-C-0038 with the U.S. Army Materials Technology Laboratory. Estane 5707F-1 also showed excellent interfacial adhesion and structural integrity required for material helmets. The typical properties of Estane 5707F-1 are shown in Table 3.2.1-1.

(2) Dispercoll E-585

Dispercoll E-585 is one of several Dispercoll polyurethane dispersions manufactured by Mobay Corporation, Pittsburgh, Pennsylvania. Dispercoll E-585 is an aliphatic polyester polyurethane based on hexamethylene di-isocyanate and isophorone di-isocyanate, and is in an aqueous dispersion form. This resin is used as an adhesive to bond textiles, plastics, and wood. Being an aqueous dispersion, this resin has some advantages over Estane 5707F-1 during the prepregging process as regards environmental hazards such as solvent emission in the atmosphere.

Dispercoll E-585 (improved grade of E-583) also has been evaluated together with Estane 5707F-1 under Contract DAAL04-87-C-0038 for the purpose of replacing Estane 5707F-1. The ballistic performance and properties of Dispercoll E-585 are comparable to those of Estane 5707F-1. The typical properties of Dispercoll E-585 are shown in Table 3.2.1-1 together with Estane 5707F-1. In this program, Dispercoll E-585 is used as a thermoplastic polyurethane matrix.

Table 3.2.1-1 Typical Properties of Estane and Dispercoll

Property	Estane 5707F-1	Dispercoll E-585
Tensile Properties Strength, psi	6,100	7,200
Modulus (300%), psi	2,100	2,350
Elongation, %	850	620
Glass Transition Temperature °C	-45	-46

3.2.2 Melamine-Formaldehyde

The melamine-formaldehyde (M-F) resin selected was Cymel 303, a commercial grade in liquid form produced by American Cyanamid, Wayne, New Jersey. Melamine-formaldehyde is a thermoset resin used as a molding compound, wood adhesive, laminating coating, and textile-treating resin. Among the advantages of melamine-formaldehyde are:

- easy fabrication by economical molding methods;
- rigidity and hardness;
- abrasion and scratch resistance;
- no tendency to become brittle at sub-zero Celsius temperatures;
- high resistance to hot water, common organic solvents, oils and greases, weak alkalis, and acids;
- a wide range of colors.

The typical properties of Cymel 303 are shown in Table 3.2.2-1. This resin is very stable at room temperature but crosslinks in the presence of a strong proton acid catalyst. The catalyst chosen was Cycat 4040 (para-toluene sulfonic acid).

Table 3.2.2-1 Typical Characteristics of Cymel 303

Appearance	Clear viscous liquid
Non-volatile, % by wt.	98.0 minimum
Specific gravity, 25°C	1.2
Flash point, °F	>200
Free formaldehyde, %	0.5 maximum

3.2.3 Vinyl Ester

(1) Derakane 8084

Derakane resins, manufactured by Dow Chemical Company, Midland, Michigan, are free radical curable liquid thermosetting resins. They are manufactured by reacting selected bisphenol-A epoxy resins with vinyl terminated acids, and diluting them with styrene. Derakane 8084 is a tough vinyl ester resin derived by introducing a reactive elastomer into the vinylester molecular structure. This vinyl ester exhibits excellent chemical resistance and high impact resistance. In addition, this resin exhibits adhesive properties, low heat of reaction during cure, and reduced

shrinkage. Diallyl phthalate and a peroxide were used as an additive and initiator, respectively, in our resin formulation. The Derakane 8084 resin system showed good ballistic performance with acceptable structural stability and molding cycle, but its adhesion to Spectra fiber required improvement. The typical properties of Derakane 8084 are shown in Table 3.2.3-1.

Table 3.2.3-1 Typical Properties of Derakane Resins

Viscosity @ 77°F, cpa	375
Flash Point	82.4
Specific gravity	1.02
Percent styrene	40
Tensile strength, psi	10,000
Tensile modulus, psi	460,000
Elongation, %	10-12
Flexural strength, psi	17,000
Flexural modulus, psi	440,000

Note: mechanical properties obtained on 1/8 inch casting.

3.2.4 Vinyl Ester/Polyurethane System

Near the completion of Phase II, AlliedSignal personnel pursuing another non-funded government program discovered a resin system consisting of thermoplastic polyurethane/thermoset vinylester hybrid system (PU/VE) which was highly suitable as a matrix material in this program. The characteristics and properties of PU/VE systems used for two stage coating are similar to the blends of polyurethane (Dispercoll E-585) and vinyl ester (Derakane 8084) described previously.

3.3 PROCESSIBILITY OF POTENTIAL RESIN SYSTEMS

In order to identify promising resins for the Spectra fabrics, the potential resins systems selected were screened to evaluate their performance. The key characteristics evaluated in this screening process were prepreggability, moldability, and ballistic performance. Each resin system was impregnated onto standard Spectra 900 fabric of 21 x 21 or Spectra 1000 fabric of 34 x 34 plain weave. The prepreg was then molded into a 12 inch x 12 inch panel. Ballistic performance, V₅₀,

was determined using 17 grain, .22 caliber fragment simulating projectiles (FSP) in accordance with MIL-P-46593A (MU).

3.3.1 Shelf Life Measurement

The shelf life of the thermoset resin systems, melamine-formaldehyde, 50/50 PVAc/M-F and vinylester, was evaluated by aging the prepreps of each resin at ambient temperature and then subjecting the composites from this aged resin to ballistic evaluation. The results are shown in Table 3.3.1-1. As can be seen, there is no indication of deterioration in ballistic performance due to aging and no difficulties were encountered during molding the panels. It is concluded that these resins have a shelf life longer than ninety (90) days at room temperature.

Table 3.3.1-1 Shelf Life of Thermoset Resins Ballistic Performance
V₅₀ (SEAT, J.m²/kg)*

Resin	Control	30 Days	60 Days	90 Days
Melamine (M-F)	1987(22.2)	1868(19.0)	1961(21.4)	2030(23.3)
50/50 PVAc M-F	1906(21.1)	1911(20.8)	1972(22.4)	1918(21.3)
Vinylester	1920(23.6)	1980(25.0)	1981(25.1)	1923(23.7)
Polyurethane/vinylester	2067(26.9)	--	--	--

*SEAT: Specific Energy Absorption Total

3.3.2 Curing Behavior

Evaluating the curing behavior of the thermosets included examining the gel time and heat of reaction during the curing reaction. The resins evaluated were melamine (Cymel 303), 50/50 blend of Cymel 303 and polyvinyl acetate (Vinac XX-210), and vinylester (Derakane 8084). The results are discussed in the following:

Gel Time Determination: The gel time was determined using a Brookfield viscometer (Model HATD, spindle 29BS) by measuring the viscosity of the resin during curing. The sample of resin was placed in a small cylinder which resided in a

temperature controlled batch. The viscosity (torque) of the resin sample was then continuously measured until the resin became a gel at which point the torque could no longer be measured. The gel time of the resin formulations were measured at various temperatures and the results are shown in Table 3.3.2-1. The gel time of vinylester at lower temperatures (52°C) was the longest, however at the higher molding temperature (100+°C) vinylester has the shortest gel time. This is desirable for the molding process.

Heat of Reaction Measurement: Heat of reaction is the heat generated during a chemical reaction during crosslinking. There are no exothermic reactions during the molding of the thermoplastic resins. The heat of reaction of thermoset resins was measured using a differential scanning calorimetry (DSC) method. The resin systems measured were Melamine-formaldehyde 50/50 PVAc and Derakane 8084 vinylester. Figures 3.3.2-1 to 3.3.2-8 show the thermograms of the heat of reaction measurement. In order to accurately measure the heat of reaction, the measurement was carried out under pressure to suppress the evaporation of reaction by-products. Table 3.3.2-2 summarizes the heat of reaction of resins measured.

As can be seen from the thermograms (Figures 3.3.2-1 to 3.3.2-8) the exothermic peaks of these resins are broad except for the vinylester, suggesting that heat is slowly generated during the entire reaction period. The 50/50 blend of polyvinyl acetate and melamine showed extremely slow heat generation and therefore, the heat of reaction was undetectable by the DSC method used. On the other hand, the vinylester showed a sharp exothermic peak, indicating high heat generation during a short period of time. However, no excessive temperature rise was observed during fabrication of vinylester test panels or helmets.

Sample: A1803-21B (TABB-1019)
Size: 54.3000 mg
Method: Initial heat up to 250°C
Comment: 20°C/Min in Argon - Open Aluminum Pan
- 50 PSI Pressure

File: KL1019DSC.05
Operator: JJB MODULE 2
Run Date: 07/26/88 13:20

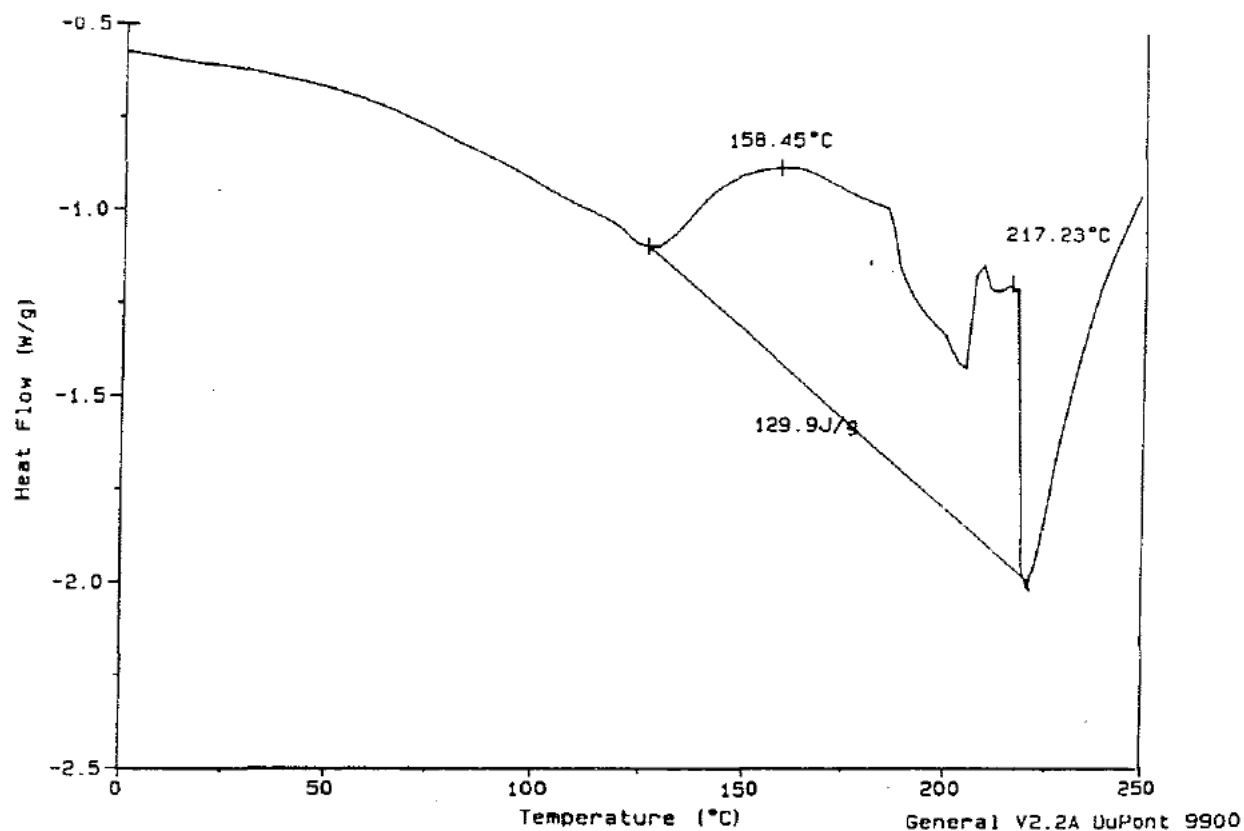


Figure 3.3.2-1 Thermogram for Measuring Exotherm of Melamine Formaldehyde at 50 psi

Sample: A1803-21B (TABB-1019)
Size: 77.1000 mg
Method: Initial heat up to 250°C
Comment: 20°C/Min in Argon - Open Aluminum Pan
- 100 PSI Pressure

File: KL1019DSC.03

Operator: JJB MODULE 2

Run Date: 07/26/88 09:18

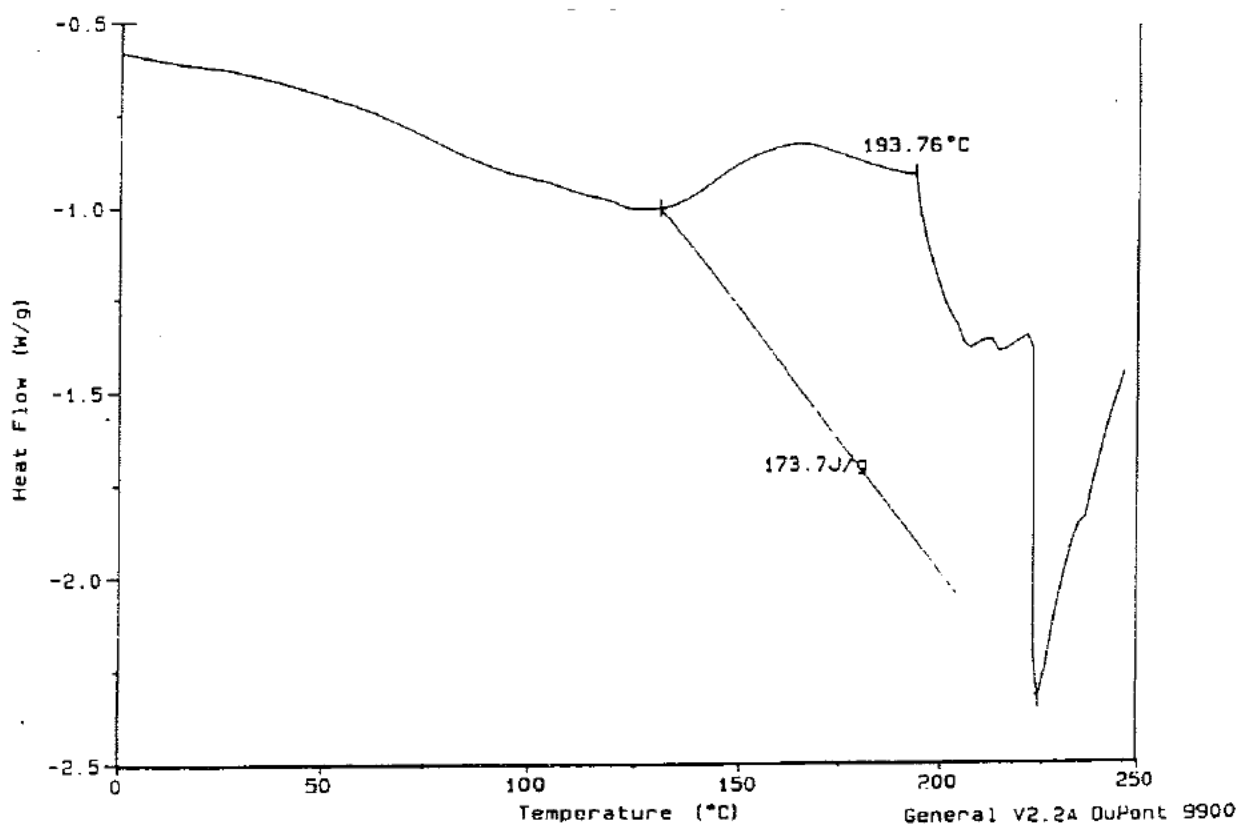


Figure 3.3.2-2 Thermogram for Measuring Exotherm of Melamine-Formaldehyde at 100 psi

Sample: A1803-21B (TABB-1019)
Size: 50.6000 mg
Method: Initial heat up to 250°C
Comment: 20°C/Min in Argon - Open Aluminum Pan
- 500 PSI Pressure

File: KL1019DSC.01
Operator: JJB MODULE 2
Run Date: 07/25/88 14:49

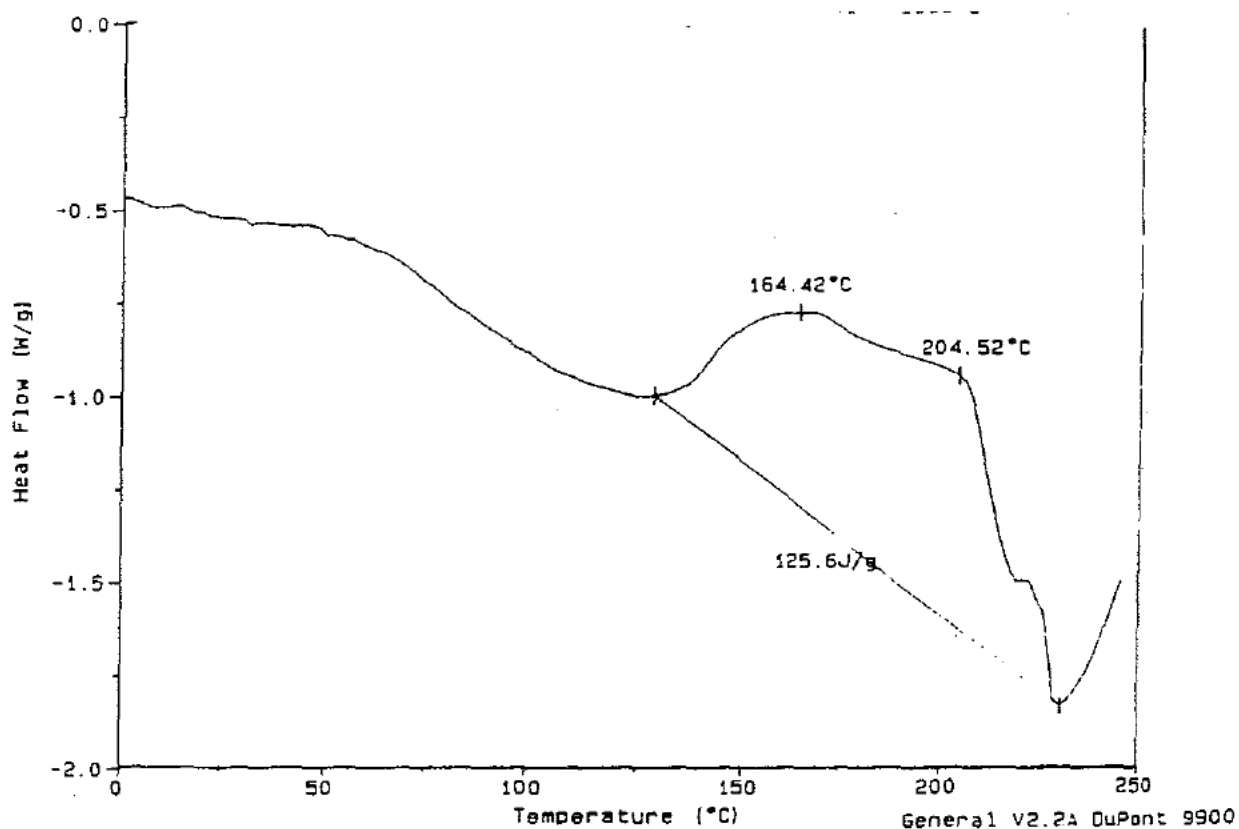


Figure 3.3.2-3 Thermogram for Measuring Exotherm of Melamine-formaldehyde at 500 psi

Sample: A1803-21B (TABB-1019)
Size: 63.8000 mg
Method: Initial heat up to 250°C
Comment: 20°C/Min in Argon - Open Aluminum Pan
- 500 PSI Pressure

File: KL1019DSC.02
Operator: JJB MODULE 2
Run Date: 07/25/88 15:59

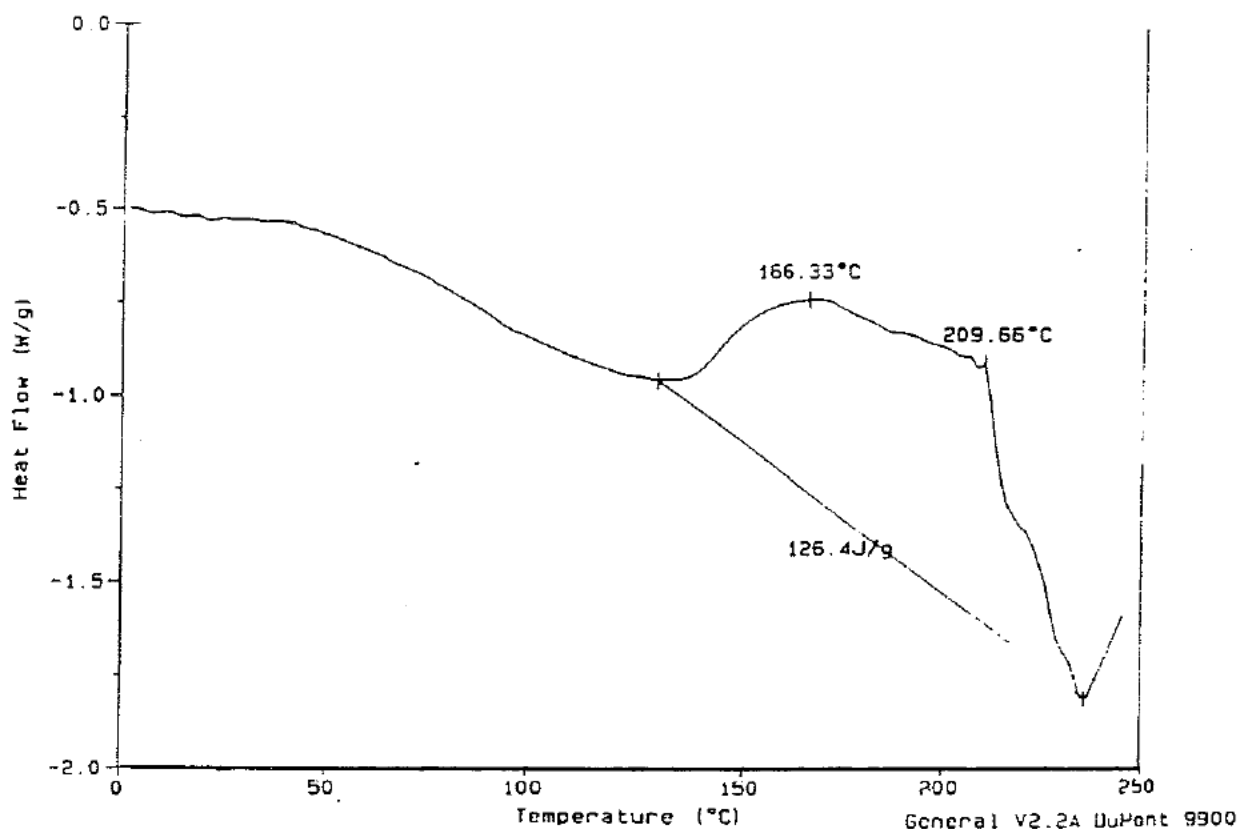


Figure 3.3.2-4 Thermogram for Measuring Exotherm of Melamine-Formaldehyde at 500 psi (repeat)

Sample: A1803-21B (TABB-1019)
Size: 57.6000 mg
Method: Initial heat up to 250°C
Comment: 20°C/Min in Argon - Open Aluminum Pan
- 700 PSI Pressure

File: KL1019DSC.04
Operator: JJB MODULE 2
Run Date: 07/26/88 10:04

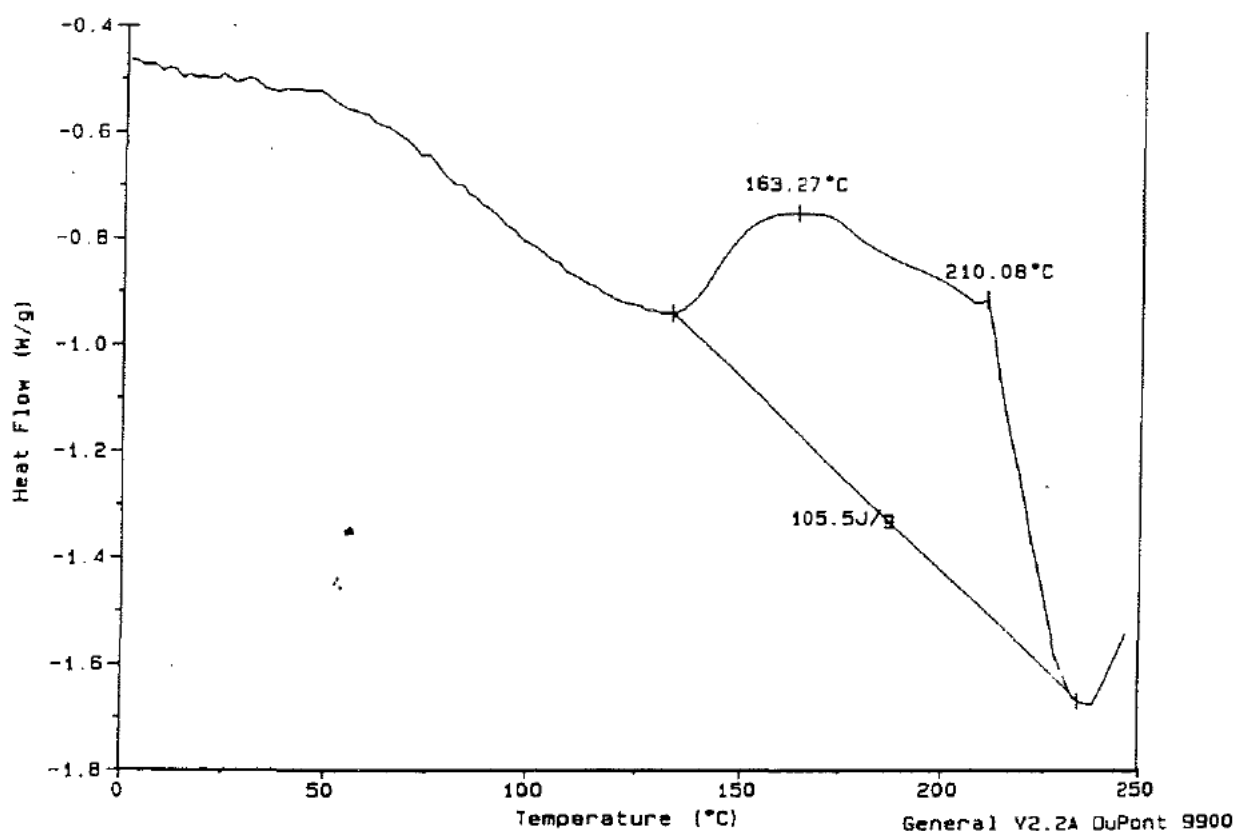


Figure 3.3.2-5 Thermogram for Measuring Exotherm of Melamine-Formaldehyde at 700 psi

Sample: A1803-21A (TABB-1018)
Size: 27.2000 mg
Method: Initial heat up to 250°C
Comment: 20°C/Min in Argon - Open Aluminum Pan
- 500 PSI Pressure

File: KL1018DSC.01
Operator: JJB MODULE 2
Run Date: 07/25/88 14:23

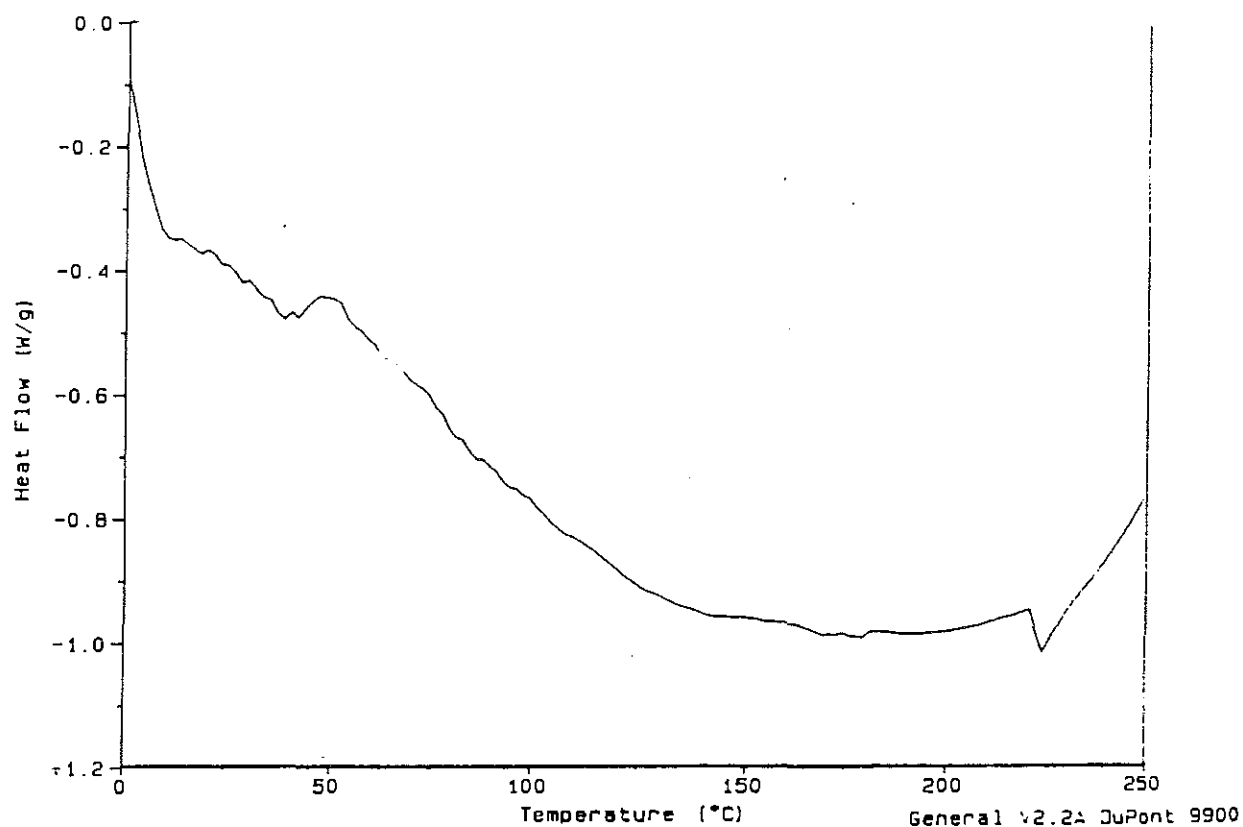


Figure 3.3.2-6 Thermogram for Measuring Exotherm of 50/50 PVAc and M-F at 500 psi

Sample: A1803-21A (TABB-1018)

Size: 34.5000 mg

Method: Initial heat up to 250°C

Comment: 20°C/Min in Argon - Open Aluminum Pan
- 700 PSI Pressure

File: KL1018DSC.02

Operator: JJB MODULE 2

Run Date: 07/26/88 08:36

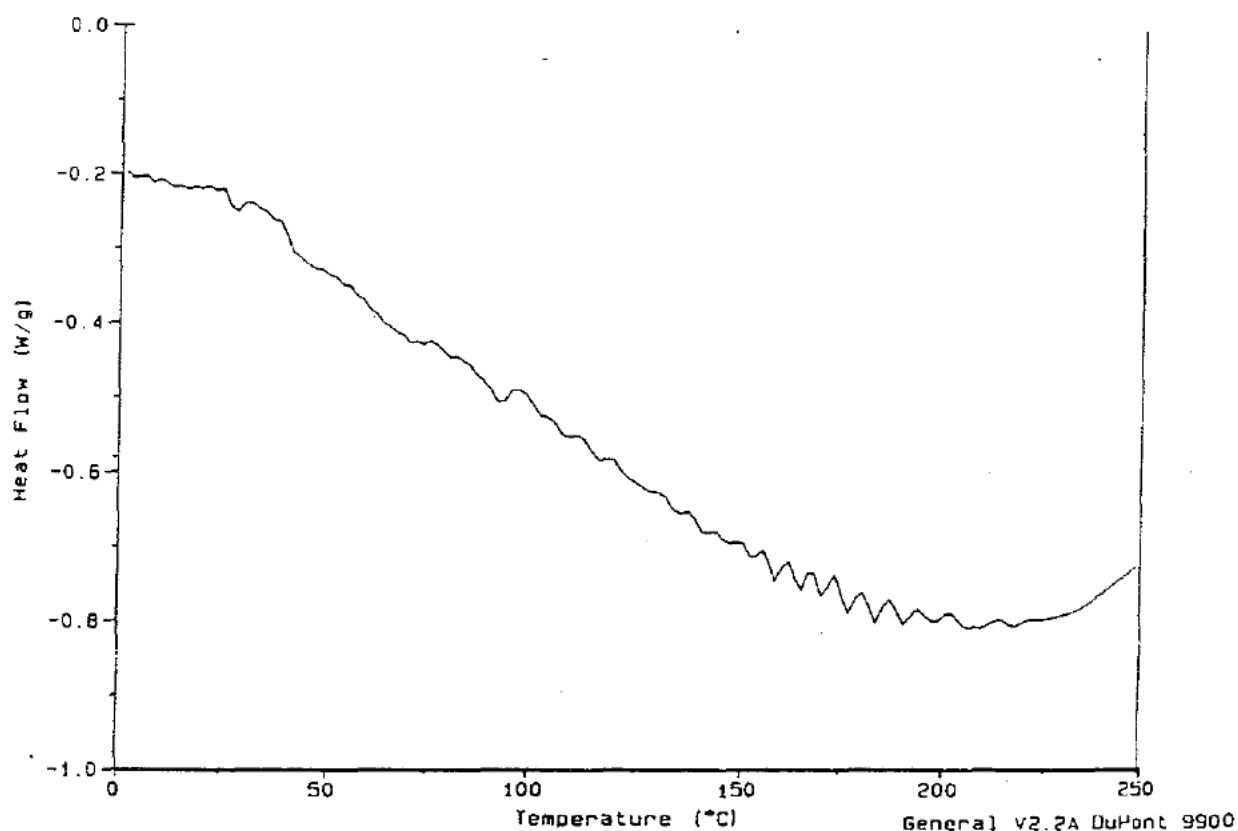


Figure 3.3.2-7 Thermogram for Measuring Exotherm of 50/50 PVAc and M-F at 700 psi

Sample: 8084 DAP (LUB 256) (TABB-1145)
Size: 30.5000 mg
Method: Initial heat up to 350°C
Comment: 20°C/Min in Argon - Sealed Stainless Steel
Pan

File: KL1145DSC.01
Operator: JJB MODULE 1
Run Date: 08/16/88 15:09

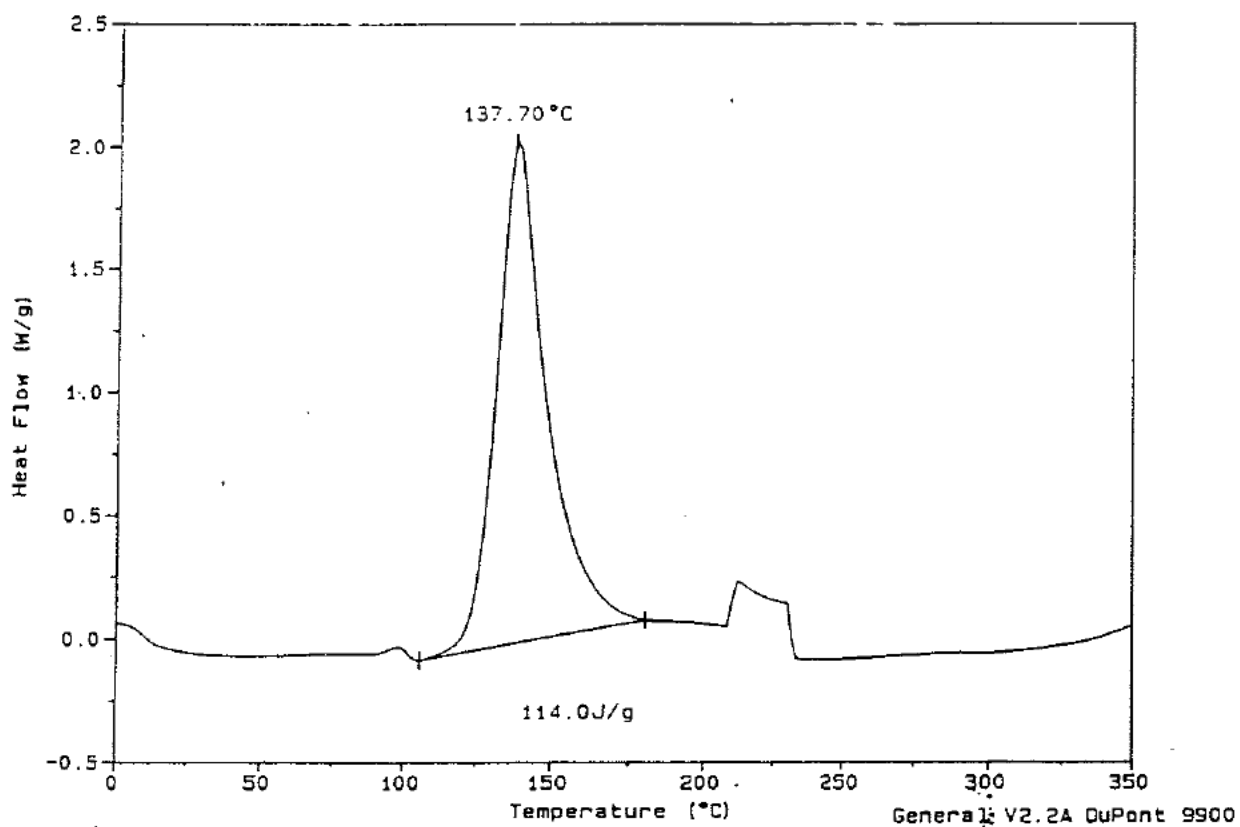


Figure 3.3.2-8 Thermogram for Measuring Exotherm of Vinylester at 15 psi

Table 3.3.2-1 Gel Time of Thermoset Systems Resin System (Min)

Temperature °C	M-F	50/50 PVAc/M-F	Vinyl Ester
37	--	2280	--
52	320	540	1560
77	--	60	57
100	140	15	7
143	27	5	--

Table 3.3.2-2 Heat of Reaction Thermoset Systems

Resin System	Pressure (psi)	Heat of Reaction (joules.gram)
Melamine-formaldehyde (M-F)	50	129.9
	100	173.7
	500	126.4
	500	125.6
	700	105.5
50/50 PVAc/M-F	500	--
	700	--
Vinyl ester (VE)	15	114.0
PU/VE	15	≤114.0

3.3.3 Laboratory Scale Impregnation

Impregnation of each resin was accomplished in a small bench-scale process. The Spectra fabric was cut into a square of 12 inches x 12 inches. The fabric square was immersed in the resin formulation so that the fabric could be completely wetted and impregnated with the resin. The immersion time varied from five (5) to ten (10) minutes depending on the resin system. The impregnated fabric was then dried at room temperature to yield a prepreg.

Each resin formulation was prepared differently depending upon the nature and characteristics of the resin. Many of the resins evaluated were in the form of a water-based emulsion or dispersion. These emulsions were diluted with water to give the desired solid content for the required resin pick-up during the impregnation process. Other forms of resin, such as liquid or solid, were dissolved using an

appropriate solvent to yield the desired concentration for resin pick-up. The resin content in the prepreg was controlled by the concentration of resin in the formulation.

3.3.4 Impregnation on a Commercial Scale

During the screening and evaluation stage, resin impregnation of the Spectra fabric was accomplished in a small bench-scale process. In order to assess the prepreggability of those most promising resins in a large-scale impregnation process, prepregging experiments were made using the commercial prepregging line of Westinghouse Inc., Bedford, Pennsylvania. Westinghouse's prepregging process is a typical continuous impregnation process capable of handling various types of fabrics and resins.

In this process the fabric to be impregnated is pulled from a roll and passed through a predryer at 60°C to drive off moisture. The predried fabric is then passed through a emersion bath containing the resin formulation to impregnate the resin on the fabric. The wet impregnated fabric is dried while passing through an oven at 70°C to yield a prepreg.

Because the polyurethane and 50/50 blend of polyvinyl acetate and melamine systems are water based emulsions, the concentration of resin in this system is adjusted by adding water. The vinyl ester resin was diluted using a solvent mixture of acetone and isopropanol. The resin pick-up was controlled by the concentration of resin and roll metering. The typical formulations to yield about 20 wt% resin content in prepreg are shown in Table 3.3.4-1 and the processing conditions are shown in Table 3.3.4-2

Table 3.3.4-1 Typical Formulations to Yield About 20 Wt. % Resin Content

Polyurethane	Dispercoll E-585	80 parts
	Water	20 parts
50/50 PVAc/M-F	Vinac XX-210	34 parts
	Cymel 303	18 parts
	Cycat 4040	1.5 parts
	Methanol	9 parts
	Water	32 parts
Vinyl ester	Derakane 8084	100 parts
	Diallyl phthalate	20 parts
	Lupersol	0.6 parts
	Acetone	50 parts
	Isopropanol	50 parts

Table 3.3.4-2 Processing Conditions for Prepregging

Resin	Take-up Speed ft/min	Predryer		Drying Oven Temperatures, °C			
				#1 Oven		#2 Oven	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Polyurethane	6	58	86	55	67	84	36
50/50 PVAc/M-F	6	58	86	55	67	84	36
Vinylester	6	58	86	55	67	84	36
PU/VE	6	58	----	----	----	----	----

3.3.5 Impregnation On AlliedSignal's 60 inch Prepreg Line

A new 60 inch wide prepreg machine which was designed in AlliedSignal's Structural Polymer Laboratory, became operational January 1989. Adjustments were made to process prepregs made from the PU/VE resin to be used in this program. This machine was capable of producing both uniaxial or fabric prepregs of 60 inch maximum width at commercial-scale quantities. The schematic drawing of the machine is illustrated in Figure 3.3.5-1.

1. 1000 Position Creel
2. Coarse Comb
3. Fine Comb
4. Spreader Bars
5. Release Paper Unwind
6. Paper Tension Control (2)
7. First Smoother Nips

8. Reciprocating Resin Coater
9. Second Smoother Nips
10. Heating Platen
11. Cooling Platen
12. Oven Nips
13. Oven
14. First Pull Roll

15. Web Aligning Steering Roll
16. Slitter
17. Second Pull Roll
18. Prepreg Winder
19. Cloth Unwind
20. Knife Coater

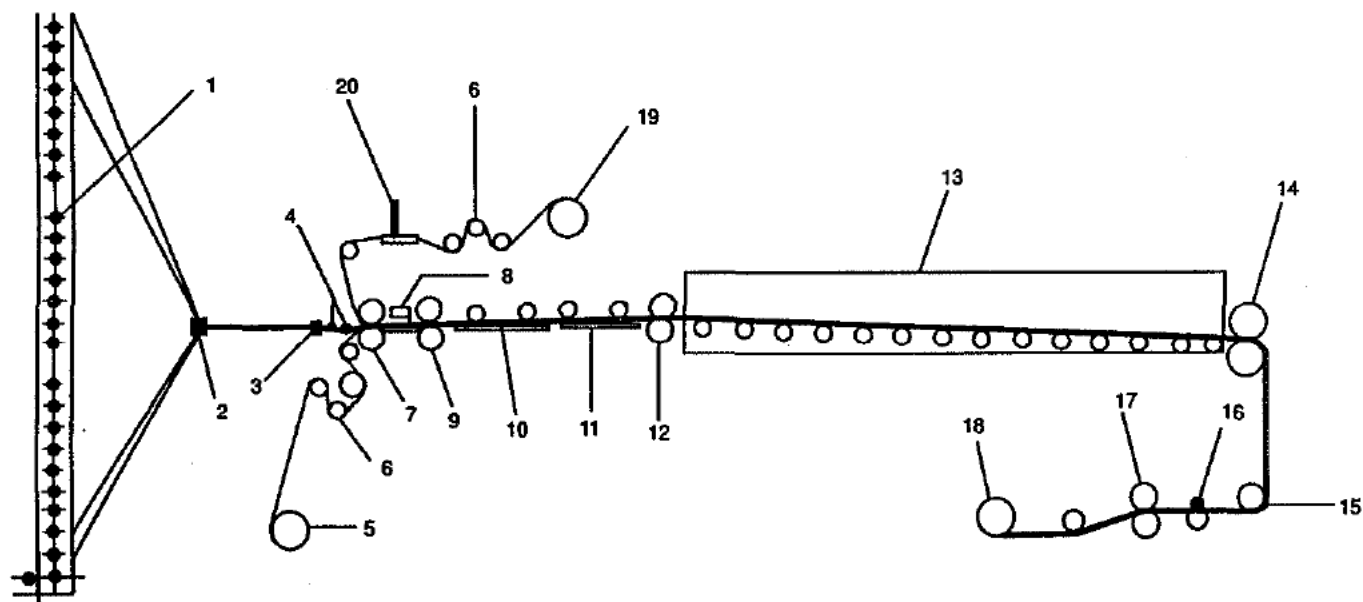


Figure 3.3.5-1 Schematic Drawing of AlliedSignal's 60-inch Prepreg Line

3.3.6 Panel Fabrication Using Allied's Fold-Stack Machine

An innovative prepreg Fold and Stack machine was conceived and built by AlliedSignal personnel (not funded by this program) to fold-and-stack prepregs into composite precursors. With this innovative piece of equipment, the time consuming manual cut-and-stack procedure was eliminated.

The fold-and-stack sequence is approximately 10 times faster than the manual handling by personnel. Adjustments were made to the fold-and-stack equipment to fold-and-stack uniaxial or fabric prepregs in a 0°/90° orientation. Using this fold-and-stack equipment and the 60-inch wide prepreg line, production costs for Spectra composites were significantly reduced.

3.3.7 Molding Procedure and Temperature of Ballistic Panels

Ballistic panels were fabricated by compression molding with a lamination press. The desired number of plies of 12 inch x 12 inch prepregs were stacked and molded in the lamination press at a proper molding pressure, temperature and molding cycle. The area density of fiber (AD) in the panel was determined by the number of plies of the fabric and the total area density (ADT) was determined by both the resin content and the amount of the fabric. The molding temperature and molding cycle were varied depending on the resin system. However, the molding temperature was maintained at less than 125°C, in order to not degrade the Spectra fabric. We determined that molding pressure influenced the performance and structural integrity of the panel. i.e., a high molding pressure (> 400 psi) resulted in uniform consolidation and hence better structural integrity during V₅₀ testing.

SECTION 4.0

MATERIAL PROPERTY EVALUATION

4.1 FLEXURAL PROPERTIES

The flexural properties of Spectra panels with various matrix resins were evaluated in accordance with ASTM D 790 and the results are shown in Table 4.1-1. The formulation of each resin is also given in Table 4.1-1. The flexural strength was measured using 0.125 inch thick panels at three different temperatures. As can be seen in Table 4.1-1, the flexural strengths of these resins are comparable at room temperature although melamine-formaldehyde and PU/VE showed slightly lower strength. At -51°C, the thermoplastics, polyvinyl acetate and polyurethane have higher flexural strength than the thermosets, melamine and vinyl ester, whereas at 71°C the thermoset resins retained strength better than the thermoplastics. The strength retention of the PVAc/M-F blends varied depending upon the composition, i.e., the 50/50 of PVAc/M-F blend showed better strength retention than the 90/10 blend at 71°C.

Table 4.1-1 Flexural Properties of Spectra Panels with Various Resins

Matrix Resin	Wt% Resin	Flexural Strength (psi)		
		-51°C	22°C	71°C
Polyvinyl Acetate (PVAc)	24	11,170	6,449	1,460
Melamine Formaldehyde (M-F)	24	3,610	2,580	2,200
90/10 PVAc/M-F	24	8,940	5,120	1,230
50/50 PVAc/M-F	24	9,270	4,510	2,110
Polyurethane	24	10,380	4,260	1,020
Vinyl ester (VE)	24	8,390	5,560	3,890
50/50 PU/VE	20	5,009	2,318	1,067

4.2 SHORT BEAM SHEAR STRENGTH

In order to evaluate interlaminar strength of Spectra composites, the short beam shear test (ASTM D 2344) was used instead of ASTM D 2733, which is not suitable for composites of polymeric fibers, especially Spectra fiber composites. The short beam shear strength is a measure of interlaminar strength. The test

specimen thickness was 0.125 inch. The results of the tests are shown in Table 4.2-1. The short beam shear strength is influenced by the interfacial adhesion and, to some extent, the flexural strength of the matrix resin. The polyvinyl acetate and vinylester showed similar short beam shear strengths. This similarity seems to suggest that these resins exhibit similar interfacial strength whereas the polyurethane, melamine-formaldehyde and PU/VE have lower interfacial strength. However, caution should be exercised in interpreting these data as the interfacial adhesion of polyurethane to the Spectra fabric is much stronger than that of the vinyl ester.

Table 4.2-1 Short Beam Shear Strength of Spectra Panels with Various Resins

Matrix Resin	Wt% Resin	Flexural Strength (psi)		
		-51°C	22°C	71°C
Polyvinyl Acetate (PVAc)	24	510	470	50
Melamine Formaldehyde (M-F)	24	230	180	150
90/10 PVAc/M-F	24	720	430	130
50/50 PVAc/M-F	24	270	200	70
Polyurethane	24	7680	270	40
Vinyl ester (VE)	24	730	500	370
50/50 PU/VE	20	--	290	--

SECTION 5.0

BALLISTIC PERFORMANCE EVALUATION OF SPECTRA PANELS

As discussed previously, the properties and characteristics of the resins selected for further evaluations met most of the requirements for a matrix resin specified in the program. The prepreggability and moldability of those resins was generally acceptable. Thus, ballistic performance was the most important criterion in screening the resin systems in addition to transient deformation and delamination. The selected potential resins were evaluated for their ballistic performance to identify the most promising resin. In evaluating the ballistic performance of resins, the energy absorbed during a ballistic impact is calculated on the fiber area and the total areal density using the following equations:

$$\begin{aligned} \text{SEA} &= 1/2 \, m \, V^2 / \text{AD} \\ \text{SEAT} &= 1/2 \, m \, V^2 / \text{ADT} \end{aligned}$$

where:

- SEA = specific energy absorbed based on fiber areal density
- SEAT = specific energy absorbed based on fiber areal density total
- m = mass of projectile
- V = velocity of projectile (V_{50})
- AD = areal density of fiber (fabric)
- ADT = total areal density of ballistic panel, or shell

5.1 THE EFFECT OF POLYMER MATRIX

Spectra 1000 panels were molded with fabric, 20 x 20 plain weave, impregnated with three resin systems: vinylester, thermoplastic polyurethane (Dispercoll, E0858) and PVAc/MF (50/50). The ballistic performance, V_{50} , of panels tested with 17 grain and 64 grain FSP's are shown in Table 5.1-1.

The panel finished with vinylester resin had a marginally better SEAT (25.5 J.M²/kg) and V_{50} (2,005 fps) against 17 grain FSP than panels with either polyurethane or PVAc/MF resin. The panel with polyurethane deformed less than panels made with either vinylester or PVAc/MF resin when subjected to 64 grain RCC impacts. However, molding of panels with thermoplastic polyurethane required a cooling cycle which was not practical for commercial production. It was also noted that the ballistic advantage of Spectra panels against higher caliber projectiles, such as the 64

grain FSP, is more pronounced when compared to PASGT (control) panels. For example, Spectra panels made with vinylester resin have a SEAT of 65 J.M²/kg when impacted by a 64 grain RCC, which is 63% higher than PASGT panels with a SEAT of 40 J.M²/kg.

Table 5.1-1 Ballistic Results for Spectra Panels

	Areal Density oz/ft ²	Areal Density lbs/ft ²	V ₅₀ - FSP			Transient Deformation 64 Grain RCC (inches)
			17 grain FSP	44 grain FSP	64 grain FSP	
Vinylester	26.7	1.67	2,005 (25.2)*	1,676	1,662 (65)*	0.90
Polyurethane Dispercoll E-858	28.2	1.76	1,901 (21.4)*	1,657	1,607 (57.7)*	0.75
50/50 PVAc/MF	29.2	1.83	2,100 (23.1)*	1,606	1,634 (57.4)*	1.06
PASGT (Control)	38.0	2.38	-- (21.0)	--	1,558 (40)*	0.75

*Specific energy absorption total, SEAT, (J.M²/kg)

5.1.1 Polyurethane

Polyurethanes are produced by reacting isocyanates and compounds containing hydroxyl groups as a polyols. Depending upon the structure of the isocyanate used, rigid flexible polyurethanes are obtained. Both rigid and flexible polyurethanes were evaluated. For this program, the ballistic performance of potential polyurethanes was evaluated and the results are summarized in Table 5.1.1-1 which details the formulation and molding conditions.

Table 5.1.1-1 Ballistic Performance of Polyurethane Matrix Panels

Resin System Formulation	Fiber wt%	ADT oz/ft ²	V ₅₀ ft/sec	SEA J-M ² /kg	SEAT J-M ² /kg	Molding		
						Temp °F	Time min	Press psi
Estane 5707F-1	80.0	26.9	1,999	31.2	24.9	248	20	600
Dispercoll E-585	82.0	25.9	1,982	30.9	25.4	248	20	275
Dispercoll E-585	80.0	29.8	1,881	24.8	19.9	248	20	486
Dispercoll E-585	77.7	27.7	1,853	26.8	20.8	248	20	486
Dispercoll E-585	77.7	27.6	1,812	25.7	20.0	248	20	486

Estane 5707F-1 and Dispercoll E-585 (upgraded E-583) are flexible thermoplastic polyurethanes. Impregnation of Estane with the Spectra fabric was made via a solution dipping process. The solvent used was tetrahydrofuran for Estane 5707F-1. Dispercoll E-585, an aqueous dispersion, was diluted with water to yield the desired concentration for impregnation. The impregnated fabric was then dried at room temperature. To ensure complete solidification, an excessively long molding cycle included cooling was employed.

Estane and Dispercoll appeared very promising as the matrix resin for the Spectra fabric, judging from the SEA and SEAT values. We determined that Estane 5707F-1 and Dispercoll E-585 (or E-583) show excellent bonding to Spectra fabrics, and thus helmets fabricated from these resins should maintain excellent structural integrity during use at temperatures below 70°C. However, a mold cooling cycle was required for thermoplastic type matrix resins.

5.1.2 Melamine-formaldehyde

Melamine-formaldehyde is a thermoset resin and thus will give high temperature resistance. The ballistic performance of these resin matrix panels is shown in Table 5.1.3-1.

The V₅₀ ballistic limit against the 17 grain, .22 caliber Fragment Simulating Projectile (FSP) is about 1,900 feet per second at an areal density of 25 ounces per square foot. As the areal density increases to 31 ounces per square foot, the V₅₀ reaches 2,073 feet per second. It is important to point out that the V₅₀ of this system can be further improved if a better (stronger) Spectra 1000 fabric is used.

There is reason to believe that the fabric used in this screening experiment had a lower tenacity (strength) than that of regular Spectra 1000 fabric, because of some variation in the weaving.

5.1.3 Blends of Melamine and Polyvinyl Acetate

As shown in Tables 5.1.3-1 and 5.1.3-2, polyvinyl acetate (PVAc) and melamine resins were determined to be promising resin systems for producing Spectra fabric helmets. As mentioned previously, PVAc is an excellent adhesive for a variety of porous and nonporous surfaces including cloth. However, PVAc is a thermoplastic and tends to soften at elevated temperatures, and thus may affect the structural integrity of Spectra helmets. On the other hand, melamine, being a thermoset, gives better rigidity, hardness, solvent resistance, high temperature resistance with a self extinguishing characteristic. Moreover, melamine is capable of reacting with several nucleophiles, such as COOH , $-\text{OH}$ or $-\text{CONH}_2$, to form a cross linked polymer network. Melamine also forms a compatible system with various resins such as PAVc, epoxies or polyacrylics. Hence, the melamine-PVAc system not only forms a compatible resin system but also crosslinks after the PVAc is hydrolyzed to produce polyvinyl alcohol, by methanol evolved during the crosslinking reaction.

Therefore, the blend of melamine and PVAc had a good balance of toughness and rigidity at elevated temperatures. Based on the property requirements, two compositions, 90/10 PVAc melamine and 50/50 PVAc/melamine, were selected for evaluation.

Table 5.1.3-1 Ballistic Performance of Cymel 303 Matrix Resin Panels

Resin System Formulation	Fiber Wt%	ADT oz/ft ²	V ₅₀ ft/sec	SEA Jm ² /Kg	SEAT Jm ² /Kg	Molding		
						Temp °F	Time min	Press psi
Cymel 303 Cycal 4040 ^a (2.5 phr)	85.9	25.3	1,882	26.9	23.5	248	360	139
Cymel 303 Cycal 4040 (2.5 phr)	83.1	30.4	1,985	26.3	21.7	248	240	139
Cymel 303 Cycal 4040 (3.0 phr) Microplex (1 phr) Ficel (1 hr)	83.5	31.0	2,073	28.7	23.3	248	120	42
Cymel 303 Cycal 4040 (3.0 phr) Microplex (1 phr) Ficel (1 phr)	83.2	30.5	1,919	24.6	20.2	248	120	139
Cymel 303 Cycal 4040 (3.0 phr) Microplex (1 phr) Ficel (1 phr)	79.2	32.5	2,004	26.8	20.7	248	120	139

Tables 5.1.3-2 and 5.1.3-3 list the results of ballistic testing with PVAc/melamine 90/10 and 50/50 systems, respectively. Both blends exhibited similar ballistic performance; however, their structural integrity and resistance to environmental resistance differed. The 50/50 blend was favored in consideration of structural integrity and temperature resistance.

Also, these blends showed comparable ballistic performance compared to their component resins, but the behavior and structural integrity of these blends differed from those of the component resins.

Table 5.1.3-2 Ballistic Performance of 90/10 PVAc and Melamine Blend Matrix Panels

Resin System Formulation	Fiber Wt%	ADT oz/ft ²	V ₅₀ ft/sec	SEA Jm ² /Kg	SEAT Jm ² /Kg	Molding		
						Temp °F	Time min	Press psi
Vinac B-100 (90 pts) Cymel 303 (10 pts) Cycat 4040 (2.5 pts) Celogen XP100 (2 pts)	89.6	29.6	1,984	25.2	22.4	120	30	139
Vinac B-100 (90 pts) Cymel 303 (10 pts) Cycat 4040 (2.5 pts) Celogen XP100 (2 pts)	83.8	31.2	1,912	23.4	19.7	120	30	42
Vinac B-100 (90 pts) Cymel 303 (10 pts) Cycat 4040 (2.5 pts) Celogen XP100 (2 pts)	89.6	28.1	2,025	27.6	24.4	120	30	700
Vinac B-100 (90 pts) Cymel 303 (10 pts) Cycat 4040 (3 pts)	86.9	29.0	1,985	26.5	22.8	120	60	486

Table 5.1.3-3 Ballistic Performance of 50/50 PVAc and Melamine Blend Matrix Panels

Resin System Formulation	Fiber Wt%	ADT oz/ft ²	V ₅₀ ft/sec	SEA Jm ² /Kg	SEAT Jm ² /Kg	Molding		
						Temp °F	Time min	Press psi
Vinac XX-210 (50 pts) Cymel 303 (50 pts) Cycat 4040 (3 pts)	87.8	28.9	1,906	24.5	21.1	120	60	486
Vinac XX-210 (50 pts) Cymel 303 (50 pts) Cycat 4040 (3 pts)	87.1	25.8	1,841	25.1	22.0	120	30	486
Vinac XX-210 (50 pts) Cymel 303 (50 pts) Cycat 4040 (3 pts)	85.2	26.3	1,788	23.7	20.4	120	30	486
Airflex 410 (50 pts) Cymel 303 (50 pts) Cycat 4040 (3 pts)	87.8	28.9	1,946	25.5	22.0	120	60	486

5.1.4 Vinylester, Phenolic/Polyvinyl Butyral and Polyurethane/Vinyl Ester Resin

Using Spectra 900 fabric (Style 903), the effect of resin systems (vinylester, phenolic/PV/B and PU/VE) on ballistic performance of panels was evaluated. All

of the panels contained 20% resin by weight. The panels with PU/VE resin had the highest ballistic V_{50} of 2,067 feet per second and a SEAT of 26.9 J.M²/kg, while panels with phenolic/PVB had the lowest V_{50} (1,890 fps) and SEAT (21 J.M²/kg). The degree of delamination for panels with the resin systems was: minimum with PU/VE, average with phenolic/PVB, and maximum with vinylester.

Table 5.1.4-1 Effect of Resin of Ballistic Performance of Spectra 900 Panels

	Resin Content Wt%	Areal Density lbs/ft ²	SEAT	
			V_{50}	J.M ² /kg
Fabric + Vinylester	20	1.70	2,010	24.8
Fabric +Phenolic/PVB	20	1.78	1,890	21.0
Fabric + Polyurethane/ Vinylester	20	1.65	2,067	26.9

5.1.5 Optimum Ratio of Polyurethane Vinylester

Experiments were conducted screening the optimum resin ratio between PU and VE. Spectra shells with PU/VE of 40/60, 50/50, 60/40 and 70/30 were molded. The moldability of shells is summarized as follows:

Shell Weight lbs	Resin Compositions PU/VE	Moldability
1.99	40/60 Sticky	Poor
2.32	50/50	Good
2.00	60/40	Good
2.06	70/30	Good

The optimum PU/VE ratio was approximately 50/50. With PU/VE ratios equal to 40/60 or less, the fabric prepreg was sticky and difficult to handle. If the PU/VE ratio was greater than 70/30, longer mold dwell due to mold cooling was required.

5.2 THE EFFECT OF RESIN CONTENT

Experimentation completed by AlliedSignal personnel indicated that the lower the percentage of the resin used, the better the ballistic property, however, at the expense of more delamination after impact. To achieve a balanced performance between ballistic V_{50} and delamination level, resin volumes of 15% to 25% were generally preferred.

5.3 THE EFFECT OF FABRIC STYLES ON BALLISTIC PERFORMANCE

In a continuation of studies on fabric styles, three new Spectra 1000 fabric styles were evaluated and the results of those evaluations are shown in Table 5.3-1. The 20 x 20 plain weave fabric showed the best V_{50} ballistic performance, consistent with results reported previously. The 4 x 4 basket weave (34 yarn ends per inch) showed similar ballistic performance to that of 34 x 34 plain weave. The satin weave (5 harness, 34 yarn ends per inch) showed much higher V_{50} than the 34 x 34 plain weave fabric.

Table 5.3-1 Effect of Fabric Style on Ballistic Performance

Fabric Styles	No. of Plies	Fiber wt%	ADT oz/ft ²	V_{50} (fps)	SEA Jm ² /kg	SEA Jm ² /kg
20 x 20 plain	52	78.7	25.1	2,123	37.6	29.5
4 x 4 basket (34/inch)	32	79.3	26.1	1,841	27.4	21.7
Satin 5 harness (34/inch)	32	79.7	42.6	1,985	33.7	26.5
34 x 34 plain	32	76.0	29.3	1,896	27.0	20.5

Resin Formulation:

Cymel 303 (40 pts)
Vinac XX-210 (20 pts)
Cycat 4040 (4 pts)
Rhoplex H-16 (20 pts)
Dispercoll E-585 (20 pts)

SECTION 6.0

ENVIRONMENTAL RESISTANCE EVALUATIONS

The effect of environmental conditioning on the ballistic performance of the panels of the most promising resins was determined. The environmental effects evaluated were dimensional stability; resistance to petroleum, oils and lubricants; resistance to ultraviolet degradation; effect of high and low temperatures; and capability of withstanding operational and storage conditions. The evaluated resin systems were polyurethane, 50/50 mixture by weight of PVAc and melamine-formaldehyde and vinyl ester. Two panels of each resin were tested for reproducibility.

6.1 DIMENSIONAL STABILITY

The dimensional stability of ballistic panels was evaluated in accordance with IL-L-41800G, Section 4.5.2. The test was performed using a autoclave/sterilizer manufactured by Consolidated Still Sterilizer (Model SSR 3A) equipped with steam pressure and temperature control devices. The test panels (ballistic panels) were placed in the sterilizer and the sterilizer was then pressurized with steam to 17 psig (260°F) and maintained at $17 \pm$ psig for 30 minutes. At the end of the test, the panels were removed from the sterilizer and examined for blisters, deformations, and any dimensional changes. Some blisters were observed with the 50/50 PVAc/M-F and polyurethane panels, but this can be easily eliminated. The tested panels were evaluated for ballistic performance; the results as shown in Figure 6.2-1. These results indicate that the ballistic performance of these resins was not affected by their exposure to high temperature steam.

6.2 RESISTANCE TO ULTRAVIOLET DEGRADATION

The effect of ultraviolet light on the ballistic performance of Spectra panels was determined using an accelerated testing method in accordance with Method No. 505.2, Procedure II. of MIL-STD810D. The testing was performed at Dset Laboratories Inc., Phoenix, Arizona where the test panels were exposed to simulated sunlight at 160°F for seven 24-hour cycles.

Table 6.2-1. Dimensional Stability of Spectra Panels

Resin	Resin (wt %)	ADT (oz/ft²)	V₅₀ (SEAT) (fps)	V₅₀ % Change	Observations
50/50 PVAc/M-F					
Control	20	29.8	1,928(20.9)		No dimensional changes
#1 Panel	20	29.8	1,966(21.8)	+1.97	Some blisters
#2 Panel	20	29.8	1,942(21.2)	+0.73	
Polyurethane					
Control	20	29.8	1,881(19.9)		No dimensional changes
#1 Panel	20	29.8	1,950(21.4)	3.67	Some blisters
#2 Panel	20	29.8	1,916(20.7)	+1.86	
Vinylester (VE)					
Control	24	28.2	1,932(22.2)		No dimensional changes
#1 Panel	24	28.2	1,941(22.4)	+0.47	No blisters
#2 Panel	24	28.2	1,964(22.9)	1.66	

The test results of ultraviolet degradation testing are shown in Table 6.2-2. After seven cycles of exposure, all the samples showed no signs of physical degradation except for the vinyl ester panels. The vinylester panels showed discoloration, indicating the degradation was occurring due to ultraviolet light. The ballistic performance of all of these resins seems to be slightly decreased, but it is not conclusive as to whether the decrease was due to ultraviolet light degradation. Note that ultraviolet light degradation can be inhibited by the use of an ultraviolet light stabilizer.

TABLE 6.2-2. Resistance to Ultraviolet Degradation

Resin	Resin (wt.)	ADT (oz/ft ²)	V ₅₀ (SEAT) (fps)	V ₅₀ % Change	Observations
50/50 PVAc/M-F					
Control	20	29.8	1928(20.9)		
# 1 Panel (A-1834-22-3)	20	29.8	1947(21.3)	+0.99	No changes
# 2 Panel (A-1834-23-5)	20	29.8	1881(19.9)	-2.44	No changes
Polyurethane					
Control	20	29.8	1881(19.9)		
#1 Panel (A-1834-22-1)	20	29.8	1810(18.4)	-3.77	No changes
#2 Panel (A-1834-23-3)	20	29.8	1809(18.4)	-3.77	Discoloring (tan)
Vinylester (VE)					
Control	24	28.2	1932(22.2)		
#1 Panel (#8)	24	28.2	1960(22.9)	+1.45	Discoloring (yellowing)
#2 Panel (A-1834-23-4)	24	28.2	1883(19.9)	-2.64	Discoloring (yellowing)

6.3 RESISTANCE TO PETROLEUM, OILS AND LUBRICANTS

The chemical resistance of Spectra panels to petroleum, oils and lubricants (POL) was evaluated in accordance with ASTM C 581. The solutions to which the test panels were exposed were Jet fuel A (ASTM D 1655, Table 1) and a 50/50 mixture by volume of toluene and isooctane (ASTM D 471, Table 2). The test panels were immersed in the solution for 24 hours. After the exposure, the tested panels were cleaned and dried with a paper towel. The panels were thoroughly examined for cracks, swelling, delamination and appearance. For both solutions, the panels of all tested resin systems exhibited no signs of cracking, swelling or change in appearance. The weight of the tested panels was measured instead of thickness as there was no sign of swelling. The tested panels were sealed in a polyethylene bag to prevent the absorbed solution in the panel from drying until ballistic performance was evaluated. The test results are shown in Tables 6.3-1 and 6.3-2. As can be seen, for all resins, there was some weight increase, but the ballistic performance was not decreased; in fact it increased slightly.

TABLE 6.3-1. Resistance to Petroleum, Oils and Lubricants (Jet Fuel A)

Resin	Resin (wt%)	ADT (oz/ft ²)	V ₅₀ (SEAT) (fps)	% Change	% Weight gain
50/50 PVAc/M-F					
Control	20	29.8	1,928(20.9)		
#1 Panel	20	29.8	2,163(26.3)	+12.2	4.5
#2 Panel	20	29.8	2,244(28.3)	+16.4	3.2
Polyurethane					
Control	20	29.8	1,881(19.9)		
#1 Panel	20	29.8	1,963(21.6)	+4.4	1.0
#2 Panel	20	29.8	1,905(20.4)	+1.3	1.1
Vinyl ester (VE)					
Control	19	26.2	1,932(23.9)		
#1 Panel	19	26.2	2,171(30.1)	+12.4	1.6
#2 Panel	19	26.2	2,113(28.5)	+9.4	1.1

**TABLE 6.3-2. Resistance to Petroleum, Oils and Lubricants
(50/50 mixture by volume of isooctane and toluene)**

Resin	Resin (wt%)	ADT (oz/ft ²)	V ₅₀ (SEAT) (fps)	% Change	% Weight gain
50/50 PVAc/M-F					
Control	20	29.8	1,928(20.9)		
#1 Panel	20	29.8	2,189(26.9)	+13.5	5.2
#2 Panel	20	29.8	2,227(27.9)	+15.5	5.3
Polyurethane					
Control	20	29.8	1,881(19.9)		
#1 Panel	20	29.8	1,995(22.4)	+6.1	2.0
#2 Panel	20	29.8	1,958(21.5)	+4.1	2.0
Vinylester (VE)					
Control	19	26.2	1,932(23.9)		
#1 Panel	19	26.2	2,135(29.1)	+10.5	0.7
#2 Panel	19	26.2	2,159(29.9)	+11.7	1.3

RESISTANCE TO HIGH AND LOW TEMPERATURES

The effects of severe climatic operating and storage conditions on the performance of Spectra panels were evaluated in accordance with AR80-78 under the following high and low temperature conditions.

Hot Climatic Operational and Storage Conditions (AR38-70, Table 2-2)

Temperature	71°C
Relative Humidity	<5%
Solar Radiation	1,120 W/m ² (20 hours on 4 hours off)
Duration	7 cycles

Cold Climate Operational and Storage Conditions (AR38-79, Table 2-8)

Temperature	-70°C (minimum -51°C)
Relative Humidity	Saturation
Solar Radiation	Negligible
Duration	72 Hours

The flexural strengths of the ballistic panels exposed to the high and low climatic operational and storage conditions shown in Table 6.4-1. Note that for the flexural strength evaluation, the test panels were exposed to 71°C in an oven for 72 hours without solar radiation.

The ballistic performance of Spectra panels exposed to the cold climatic operational and storage conditions is shown in Table 6.4-2. In a comparison of the ballistic performance of Spectra panels exposed to the hot climatic and storage conditions with the ultra violet degradation (see Table 6.2-2) the tested panels showed that they were not affected significantly by the exposure to the high or low temperatures.

**TABLE 6.4-1 Resistance to Field Climate Operation and Storage Conditions
(Flexural Strength after Exposure to Low Temperature)**

<u>Maxtix Resin</u>	<u>wt% Resin</u>	<u>Control</u>	<u>-94°F (-70°C)</u>	<u>71°C</u>
50/50 PVAc/M-F	20	3,200	2,890	3,310
Polyurethane	19	3,070	2,930	3,570
Vinyl ester	19	4,640	5,140	5,050

**TABLE 6.4-2 Resistance to Field Climate Operation and Storage Conditions
(Ballistic Performance after Exposure to Low Temperature -94°F)**

Resin	Resin (wt%)	ADT (oz/ft²)	V₅₀ (SEAT) (fps)	% Change	Observations
50/50 PVAc/M-F					
Control	20	29.8	1,928(20.9)		
#1 Panel	20	29.8	1,878(19.8)	-2.6	No changes
#2 Panel	20	29.8	1,930(21.0)	+0.1	No changes
Polyurethane					
Control	20	29.8	1,881(19.9)		
#1 Panel	20	29.8	1,929(20.1)	+2.5	No changes
#2 Panel	20	29.8	1,873(19.8)	-0.4	No changes
Vinylester (VE)					
Control	24	26.2	1,932(23.9)		
#1 Panel	24	26.2	1,905(23.2)	-1.4	No changes
#2 Panel	24	26.2	1,912(23.5)	-1.0	No changes

SECTION 7.0

HELMET SHELL FABRICATION AND PROPERTY EVALUATIONS

7.1 SELECTION OF FABRIC PREPREG PATTERNS

All of the Spectra shells studied during Phase II, Task A were molded from fabric preregs. Evaluations were carried out using two different types of geometrical patterns of blanks cut from fabric preregs.

7.1.1 Hexagon with Slits

Each prepreg fabric was cut into a hexagonal blank (or ply), then a slit was cut extending from the apex toward the center of the hexagonal blank. As successive blanks were laid up inside a cylindrical container, they were rotated slightly to stagger the positions of adjacent plies. As the laying up operation proceeded, progressively smaller blanks were laid up between adjacent relatively larger blanks.

7.1.2 Six Lobes Configuration

The fabric preregs were cut into six lobe configurations as shown in Figure 7.1.2-1. Between two neighboring lobes, the adjacent edges must overlap each other about 0.5 inch to cover the fault line or butt lines as the blanks were laid over a mold surface, or a cylindrical container, as shown in Figure 7.1.2-2. Spectra shells were molded from blanks of either hexagon or six lobe patterns. From the results of ballistic testing, the U.S. Army Materials Research Laboratory informed AlliedSignal that shells molded from blanks with six lobe patterns had more uniform ballistic distribution than the shells molded from a hexagonal pattern. As a result Allied Signal decided that shells should be fabricated from blanks of six lobe patterns for Phase II, Task A.

The blanks of six lobe configurations were laid up inside a container as shown in Figure 7.2.2-2, the adjacent blanks were rotated approximately 15° with respect to each other in order to avoid overlapping along the fault lines. As soon as the stacked blanks were removed from the container and placed on the mold surface, shown in Figure 7.1.2-3, the edges of the lobes were diverging outwardly. As the cavity mold moved downward toward the core, the edges of the lobes began to converge toward the mold surface. It

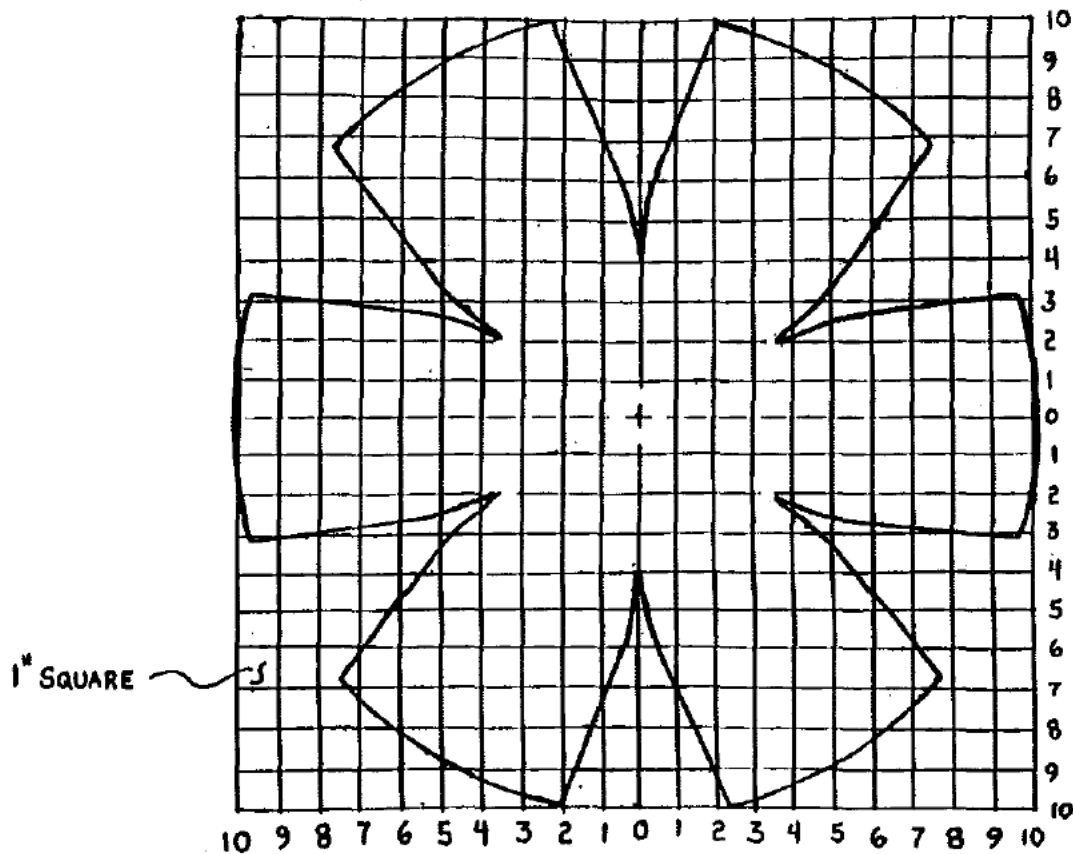


Figure 7.1.2-1. Six Lobe Fabric Prepreg Configuration.

was thought that divergence and subsequent convergence of the lobes during molding was undesirable and might cause locally non-uniform areal density, during molding. To overcome the problem, the circumferential edges of the blank laid, firstly, inside the container were taped with Kapton film, as shown in Figure 7.1.2-4. After a number of layers or blanks were subsequently laid, the blanks were then placed on the surface of the mold, Figure 7.1.2-5. Due to the constraint of the blank with Kapton strips, no edge divergence was observed. It was anticipated that the shells molded with this method will give more uniform ballistic distribution.

Several shells were fabricated with edge constraints and several others without edge constraints, under otherwise identical conditions. It was found that shells with edge constraints weighed about 10% more than shells without edge constraints. The difference in shell weight was attributed to the fact that, without edge constraint, the blanks were subjected to more tensile stretching than the blanks with edge constraint during stamping. However, more uniform ballistic performance was achieved with shells using edge constraint than without.

7.2

MOLDING PROCESS

In order to assess helmet fabrication processability, helmet shells were fabricated with the three most promising resins selected in Phase I and the new PU/VE resin discovered near the end of Phase II, Task A. Spectra 1000 fabric was used for all fabric preregs made from the three resin systems and the PU/VE resin was used with Spectra 900 fabric. The helmet fabrication procedures for these resins was basically identical except for minor changes in process conditions. The number of prepreg layers varied depending upon the weight and the thickness of the helmet which was fabricated.

Shells, fabricated with the above matrix resins, were manufactured under various conditions: mold temperature (118°C and 124°C), mold cycle time (15 minutes and 25 minutes), and a constant molding pressure of 200 tons. It was found that at temperatures greater than 124°C, pressures of more than 200 tons, and mold cycle time of more than 15 minutes, the molded shells of thermoset resins were sufficiently rigid to be removed from the mold. However, we desired to remove the shells from the mold after a molding time of approximately 13 minutes and examine the inner wall of the shells. Afterwards, the shells were returned to the mold and placed under the same pressure and temperature for an additional 2 minutes or longer for a total mold cycle time from 15 to 25 minutes. In this way, residual bubbles were eliminated.

We also demonstrated a special method of molding shells with fabric preregs containing thermoplastic resins, such as polyurethane (Dispercoll) without mold cooling cycle. However, the preregs must be preheated in an hot air oven. The detailed process to mold shells with various resins are summarized below:

Polyurethane

- a) Polyurethane prepreg was cut into a 6 lobe pattern. A total of 29 to 32 layers were used to give a shell thickness of about 0.3 inches.
- b) The 6 lobe pattern preregs were stacked to form a helmet preform. The preform helmet shell was preheated in an oven at about 200°F for 15 to 20 minutes.
- c) The preheated shell was placed in a PASGT mold and molded at a temperature of 240°F and pressure of 200 tons for 20 minutes.

The stamped shells conformed well to the desired mold configuration and we demonstrated that Spectra shells made with a thermoplastic resin could be manufactured without a mold cooling cycle with a 20 minute cycle time. The helmet shell was constructed from 30 layers of fabric prepreg weighed 2.2 pounds, and had a V_{50} of 2,038 fps and a SEAT of $25.5 \text{ J}\cdot\text{M}^2/\text{Kg}$.

50/50 Polyvinyl acetate and melamine system

- a) The 50/50 PVAc/M-F Spectra prepreg was cut into a 6 lobe pattern. A total of 29 to 32 layers were used to give a final shell thickness of 0.3 inches.
- b) The 6 lobe pattern prepregs were stacked to form a helmet preform. The preformed helmet shell was preheated in an oven at 160°F to remove moisture and volatiles.
- c) The preformed shell was molded into a helmet shell at 238°F with a pressure of 200 tons for 5 minutes. The pressure was then released to expel gases and the helmet mold was closed for 20 minutes at a pressure of 200 tons.

Vinylester

- a) The vinyl ester prepreg was cut into several different sizes of hexagonal patterns.
- b) The hexagonal pattern prepregs were stacked to form a helmet shell preform at room temperature.
- c) The preformed shell was molded at 230°F and 200 tons for 20 minutes. The molded helmet shell was then removed from the mold.

Phenolic/polyvinyl-butryal

- a) Phenolic/PV B prepregs were cut into 6-lobe pattern. A total of 29 to 31 layers were used to give a final shell thickness of about 0.35 inches.
- b) The 6-lobe pattern prepregs were stacked and preheated in an hot air oven at 110°C for 2 hours to remove volatiles.

c) The preheated shell prepreg was molded at a temperature of 116°C and 185 tons for 13 minutes, then the shell was removed from the mold. Needles were used to puncture the blisters.

d) The shell was molded with a total mold residence time of 20 minutes. The shell was removed from the mold and excessive blisters were observed. Difficulties were also encountered in removing the cured shells from the mold surface.

Polyurethane/vinylester

To study the effect of PU/VE ratios on the processibility of fabric prepregs, fabric prepregs with various PU/VE ratios, 90/10, 80/20, 70/30, 50/50, 40/60, were evaluated. Test results indicated that a mold cooling cycle is required with PU/VE ratio of 90/10. As the PU/VE ratio was increased from 70/30 to 50/50, no mold cooling cycle was required and the molded panels or helmet shell could be removed from the hot mold without any distortion of the shell. From this data, we determined that a 50/50 PU/VE ratio was optimum. With a PU/VE ratio of 50/50, a Spectra 900 test panel was molded at a pressure of 500 psi and temperature of 120°C. The mold residence time was 25 minutes. The panel areal density was 1.67 pounds per square foot and the measured V_{50} was 2,050 fps (SEAT of 26 J·M²/kg). Minimum delamination was observed after ballistic testing. The Spectra shells with PU/VE (50/50) resin were also produced with a mold cycle time of less than 25 minutes at a constant mold temperature of 116°C and pressure of 180 tons, without cooling cycle.

SECTION 8.0

BALLISTIC PERFORMANCE OF HELMET SHELLS

The medium sized PASGT helmet shells with the most promising resins, fabricated with the procedure outlined in Section 7.0 of this report, were evaluated for their ballistic performance using the 17 grain, .22 caliber fragment simulating projectile (FSPs). The results of those tests are shown in Figure 8.0-1.

The ballistic performance of the helmet shells made from 50/50 blends of PV Ac/M-F or PU/VE resin is approximately the same. However, the shells with PU/VE delaminated much less than shells made from PV Ac/M-F resin. The weight of the helmet shells exceeded the required weight of 2.2 pounds but we believe that this weight could be reduced by optimizing the processing variables in the fabrication process.

Table 8.0-1. Ballistic Performance of Spectra Helmet Shells

Matrix Resin	Number of Layers	Resin %	Weight lbs	V ₅₀ (fps)
Polyurethane (Dispercoll E-585)	30	22	2.5	2,088
50/50 Blend, PVAc/M-F	30	24	2.5	2,150
Vinyl ester (Derakane 8084)	33	22	2.3	2,130
Phenolic/PV.B	30	20	2.34	2,193
50/50 PU/VE	27	20	2.3	2,200

8.1 EFFECT OF NUMBER OF LAYERS (AREAL DENSITY) AND RESINS ON BALLISTIC PERFORMANCE

Spectra shells, constructed from 28, 29, 30, 31 and 32 layers of fabric prepreps impregnated with vinylester as the matrix-resin, were molded and submitted to H. P. White Laboratory, Street, Maryland for ballistic testing. From these results we determined the exact number of layers, or shell weight, required to meet the specified 17 grain .22 caliber FSP V₅₀ of 2,150 feet per second. For relative comparison

purposes, shells were also molded from 30 layers of Fiberite supplied fabric preregs (phenolic/pvb was the matrix-resin). However, only two shells were made due to the limited amount of preregs available from Fiberite, Inc. All of the shells were constructed from Spectra 1000 fabric, Style 952, with vinylester matrix resin.

The ballistic performance of various shells weighing from 2.15 pounds to 2.7 pounds is shown in Figure 8.1-1. The lighter weight shells were constructed from 28 fabric prepreg layers while the heavier ones from 32 layers.

The U.S. Army Natick Research, Development and Engineering Center also requested that AlliedSignal add one layer of either glass fabric or Kevlar to the helmet shell exterior surface. The purpose was to tumble test the paint adhesion to various types of surfaces (glass, fabric, Kevlar, Spectra). The results of these tests are discussed in Section 9.5 of this report.

Ballistic tests accomplished by H.P. White indicated that the V_{50} increased from 2,041 feet per second to approximately 2,150 feet per second, when the shell weight was increased from 2.2 pounds (28 layers) to 2.4 pounds (31 layers). Further increases in shell weight from 2.4 to 2.73 pounds resulted in only a marginal improvement in V_{50} (2,150 to 2,200 feet per second). Figure 8.1-2 shows the values of SEAT versus shell weight. SEAT values remain unchanged between shell weights of 2.2 to 2.4 pounds. However, SEAT values drop steeply as shell weight was increased from 2.4 to 2.8 pounds. This occurs because the medium size PASGT type mold is designed based on a constant volume. This volume is ideal for a Spectra shell of 2.2 pounds or a Kevlar shell of 2.8 pounds. Any further increase in shell weight will cause the fabric to fold and wrinkle, resulting in localized non-uniformity and lower ballistic performance values.

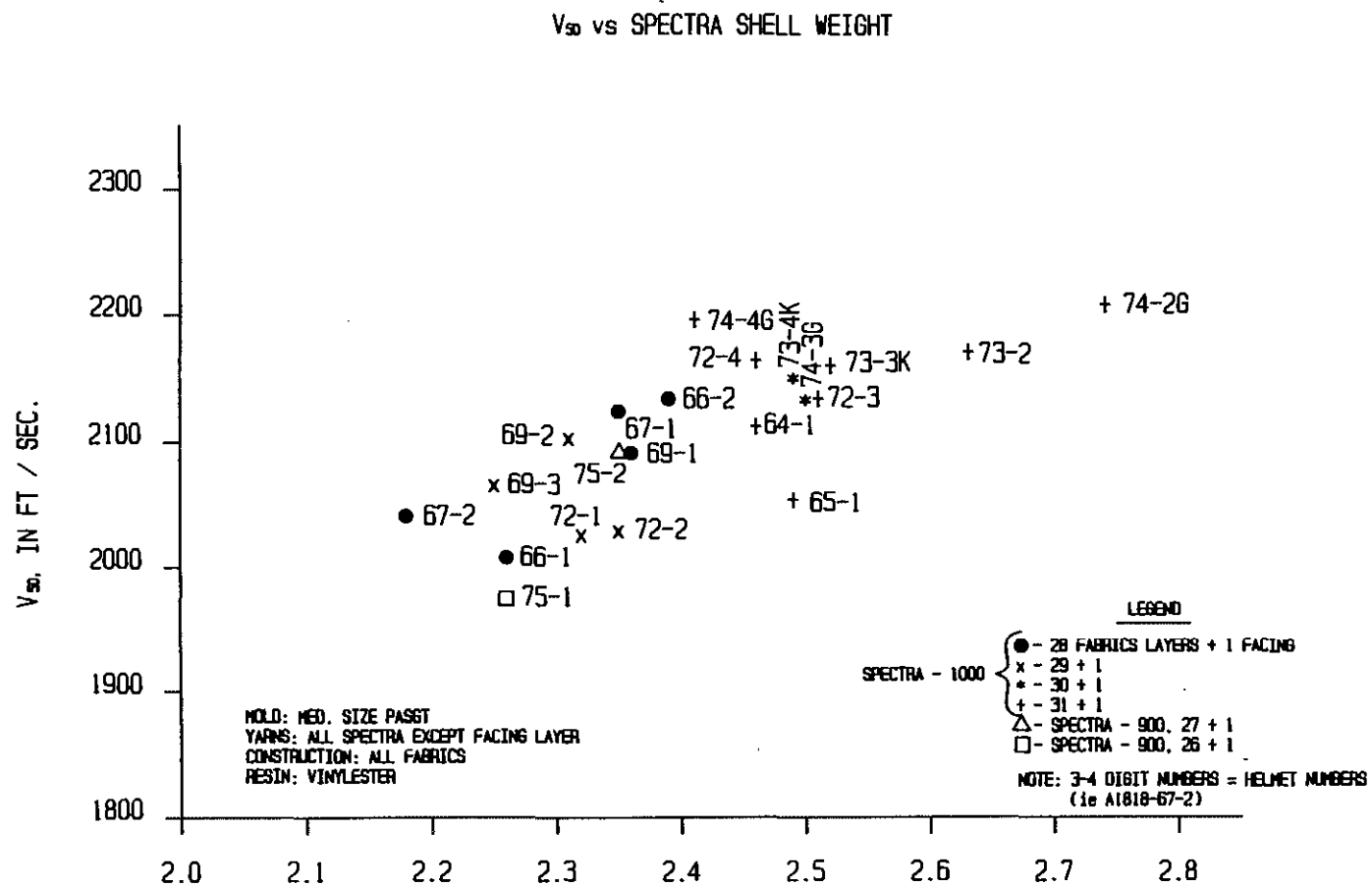


Figure 8.1-1 V₅₀ Versus Spectra Shell Weight

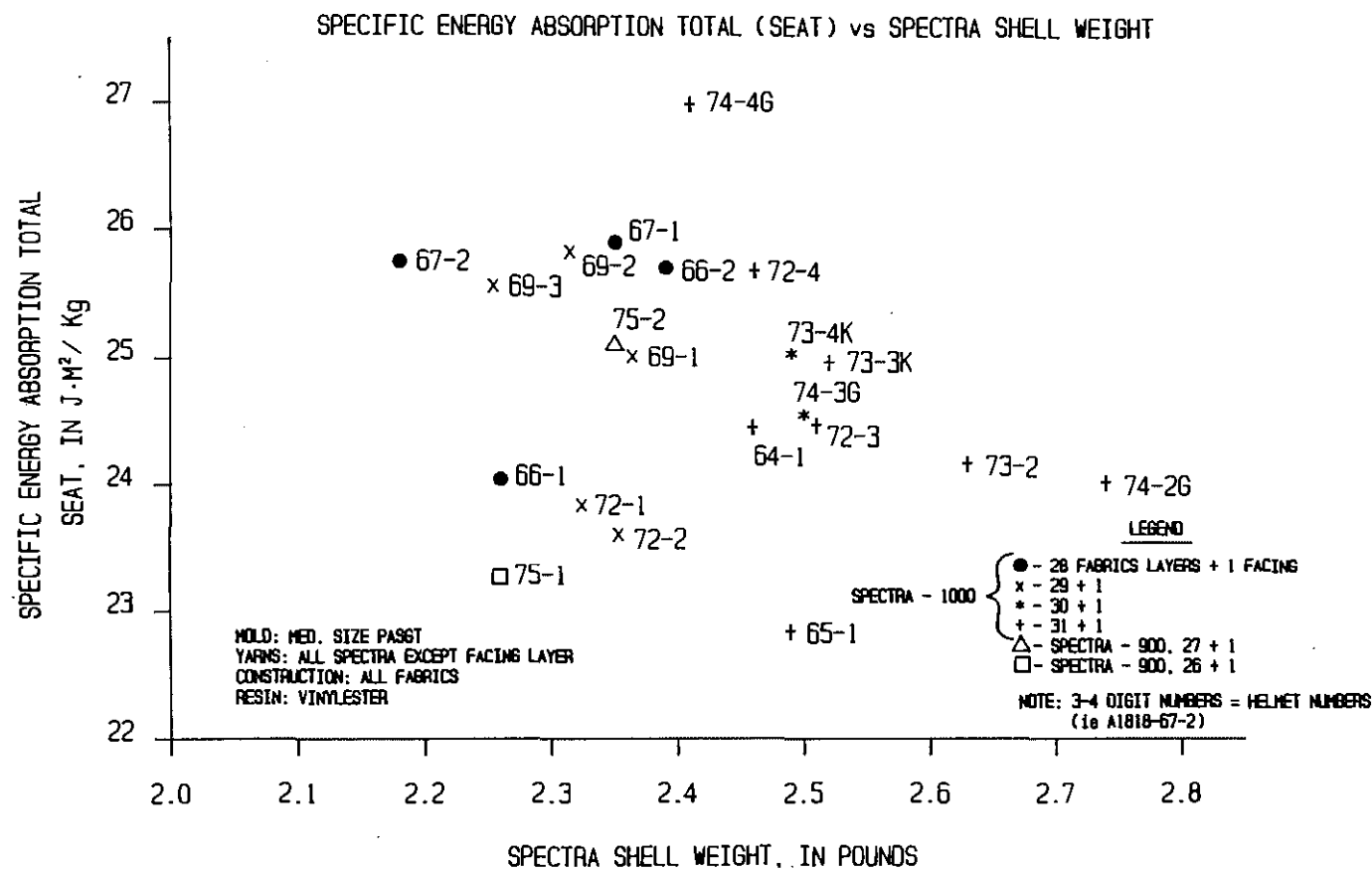


Figure 8.1-2 SEAT Versus Shell Weight

SECTION 9.0

PHASE II - TASK A - MODIFIED TEST PROGRAM FOR SPECTRA SHELLS WITH PU/VE RESIN

The original program outlined for Phase II, Task A included fabrication of 26 Spectra-1000 shells with vinylester resin and another 26 Spectra shells with phenolic/PV B resin. Twenty-six Spectra shells with vinylester resin were delivered on schedule to MTL and Natick on February 7 and 8, 1989. However, we informed the Army that test results from H. P. White Laboratory indicated that Spectra shells made with the vinylester resin delaminated when impacted by .22 fragment simulating projectiles. Therefore, a comprehensive evaluation by the U. S. Army Natick Research, Development and Engineering Center was essential to confirm the results.

The delivery of Spectra 1000 fabric prepregs with phenolic/PV B resin from Fiberite Inc. was delayed until the middle of April 1989 from the originally scheduled delivery date of January 1989. Preliminary results indicated that these shells had excessive blisters and it was difficult to remove the shells from the mold surface. Thirteen (13) Spectra shells with phenolic/PV B resin were molded and all these shells were molded using thirty-one (31) layers of Spectra 1000 fabric prepreg layers. Five (5) shells were also molded under exploratory conditions. However, blisters were still observed. All of the remaining fabric prepregs were sent back to U. S. Army Natick Research, Development and Engineering Center.

In view of the problems encountered with vinylester and phenolic/PV B resin systems, we proposed another resin system, PU/VE, which had been developed on a separate AlliedSignal program (at no cost to the government). We fabricated five shells of this system and shipped them to Natick for initial evaluations. Afterward, the U. S. Army concurred with our findings that PU/VE was indeed the most promising resin system for Spectra shells. A total of twenty-four (24) Spectra 900 shells were produced. These PU/VE resin helmet shells were forwarded to Natick. They were subsequently tested by the U.S. Army Materials Technology Laboratory and the U.S. Army Combat Systems Testing Activity, Aberdeen Proving Ground, Maryland.

9.1 PERFORMANCE EVALUATION OF SPECTRA FABRIC SHELLS BY THE U. S. ARMY

The ballistic performance of Spectra shells made with the PU/VE resin was preliminarily evaluated both by AlliedSignal and the U. S. Army (Natick). We agreed that PU/VE was the most promising resin system for Spectra helmet shells based on minimum delamination and transient deformation as well as its superior ballistic performance.

At the request of Natick, AlliedSignal made an additional 26 shells with PU/VE and submitted them to Natick for additional comprehensive evaluation before a decision was made as to which resin system should be finally chosen for Phase II - Task B, fabrication of 175 helmets. The results of the evaluation by the U. S. Army are summarized as shown in Table 9.1-1. All Spectra shell listed in Table 9.1-1 were molded at the Structural Polymer Laboratory of AlliedSignal. A six lobe configuration was used to construct all Spectra shells except those noted in Table 9.1-1.

FIBER			SPECTRA-1000		SPECTRA-900		KEVLAR	
RESIN PATTERN			PVB+PF**	VE+PU ⁺	VE+PU ⁺	VE+P U ⁺	VE+P U ⁺	PVB+PF **
LOBE PATTERN			6v	6v	6v	8v	6vv	6v
WEIGHT (POUNDS)			2.4	2.4	2.3	2.1	2.2	2.3
V50 (ft/sec)	2 gr	RCC	3,524		3,973			3,937
	17 gr	FSP		2,138	2,270	2,185	2,214	2,150
	shell	front			2,381		2,185	
	shell	back			2,368		2,220	
	shell	right			2,230		2,152	
	shell	left			2,217			
	shell	top			2,161		2,161	
	shell	average			2,271		2,180	2,150
	44 gr				1,926	1,809		1,885
	64 gr		1,683		1,978	1,873		1,558
TRANS. DEF.	44 gr	FSP*	1.73		1.50	1.49		1.55
(INCHES)	64 gr	RCC	2.72a		2.87a	3.13c		

* Average impact velocity used was 1,550 ft/sec.

a, b, c, Average impact velocities used was 1,619, 1,913 and 1,826 ft/sec respectively

** Fiberite Inc. formulation

+ Vinylester / polyurethane

v Polymer Lab pattern, 6 lobes fabric stacking: 0° and 90°

vv Polymer Lab, 6 lobes, fabric stacking 0°, +45°, 90°, -45°, plus 3 crown patches

**Table 9.1-1. Evaluation by the U.S. Army of PU/VE Resin System
Spectra Helmet Shells**

9.1.1 The Effect of Polymer Matrices

Spectra shells with PU/VE resin: The ballistic V_{50} and transient deformation values for a Spectra 900 shell (2.3 pounds) with PU/VE resin and Kevlar PASGT shell (2.8 pounds) are shown in Figure 9.1-1.

Against the projectiles with a weight of 2 grains, the Spectra shell (2.3 pounds) with PU/VE resin has the measured V_{50} of 3,973 feet per second. This performance compares favorably with that of a Kevlar shell (2.8 pounds) with a V_{50} of 3,937 feet per second.

As the sizes of the projectile is increased from 2 grains to 64 grains, the difference in ballistic performance (V_{50}) and SEAT for Spectra versus Kevlar shells become more pronounced. For example, against a 17 grain fragment simulating projectile, the Spectra shell has a V_{50} of 2,270 fps (SEAT - 30.2 J.M²/kg) as compared to a V_{50} of 2,150 fps (SEAT - 22.3 J.M²/kg) for the Kevlar shell. The Spectra shell absorb 31.4% and 55% more energy, respectively, when compared to Kevlar shells against 44 and 64 grain right circular cylinders (RCC). One plausible explanation is that the smaller sized projectiles have a tendency to push aside the adjacent yarn instead of engaging the yarn as is the case when the shells are impacted by larger size projectiles. In that case, the Spectra yarn will absorb more energy than Kevlar if the yarns are stretched to failure.

Spectra shells with PvB/PH resin: Spectra 1000 fabric prepreps made with PVS/PH resin were supplied by Fiberite for fabrication of Spectra shells. However, none of these shells which were produced with this material were free from surface defects. The ballistic performance of the shells which weighted 2.4 pounds is shown in Table 9.1-1. Against the 2 gr. RCC the V_{50} of 3,524 is slightly lower than the V_{50} of 3,937 fps for a Kevlar shell of 2.8 pounds. Against a 64 gram RCC, the 2.4 pound Spectra shell, made with PvB/PH resin, had a V_{50} of 1,683 fps, which is significantly lower than 1,873 fps and 1,978 fps measured for shells made with PU/VE weighing 2.1 and 2.3 pounds, respectively.

9.1.2 Spectra Shells with Vinylester Resin

Against 17 grain fragment simulating projectives, 2.4 pound Spectra 1000 shells made with vinylester resin had a V_{50} of 2,136 fps (SEAT of 25.6 J-M²/kg). This value is slightly lower than the ballistic V_{50} of 2,271 fps (SEAT of 30.2 J-M²/kg) for the PU/VE shell. However, Spectra shells made with vinylester resin tended to delaminate badly after impact, while the shells with PU/VE showed much less delamination.

9.2 EFFECT OF HAND LAY-UP PATTERNS

The V_{50} for 2.3 pound shells constructed from six lobes, 2.1 pound shells from 8-lobes, and 2.2 pound shells from 6-lobes with crown patches are 2,270 fps (SEAT of 30.2 J-M²/kg), 2,185 fps (30.6 J-M²/kg) and 2,214 fps (30.0 J-M²/kg), respectively. Based on specific energy absorption, there is no discernible difference in ballistic performance among shells constructed from any of the above mentioned hand lay-up patterns. This ballistic performance data was provided by the U.S. Army.

Therefore, the ballistic performance, V_{50} , of Spectra shells is not sensitive to hand lay-up patterns and it can be transferred to a commercial manufacturer with the expectation of achieving the same ballistic performance, if the same basic lobe configuration is used. However, the level of delamination is less with a helmet shell constructed from a six lobe pattern than from an eight lobe pattern. This occurs because the fabric has less edges with a six lobe pattern.

In the commercial production of helmet shells, lobe configuration is not maximized because of higher fabric waste, which may range as much as 45%. Commercial producers do not seem to be highly sensitized to the fact that shells constructed with this configuration have less tendency to delaminate. The exact patterns used commercially are, of course, proprietary. However, it is known the waste factor in commercial production ranges to about 25%, which can only be met by using "hexagons, squares and strips (US Patent 4,778,638).

9.2.1 U.S. Army Natick Research , Development and Engineering Center Evaluations of Spectra 1000 and Spectra 900 Shells

The ballistic performance, V_{50} , of Spectra shells constructed from Spectra 1000 and Spectra 900 fabric using a PU/VE resin system is shown in Column C and D of Table 9.1-1.

The Spectra 1000 shells which weighed 2.4 pounds had a V_{50} of 2,123 fps, which is less than the Spectra 900 shell which weighs 2.3 pounds with a V_{50} of 2,270 fps. These results seem contradictory to our expectation that the ballistic performance of Spectra 1000 should be better than Spectra 900, when constructed by identical process and construction conditions. One plausible explanation was that, during weaving operations, the finer denier Spectra 1000 yarns were no longer twist-free, parallel and straight, which is the key ingredient for improved ballistic results.

9.2.2 H. P. White Laboratory - Evaluations of Spectra 900 and Spectra 1000 shells

Spectra 900 and 1000 helmet shells were molded by AlliedSignal using a PU/VE 50/50 resin system. The molding clamp force was 200 tons at a temperature of 120°C. After 2 minutes of molding, the shell was removed from the mold; surface blisters were observed which were removed using needles to release entrapped air or volatile gases. Afterward, the shell was placed into the mold and the molding cycle was continued. The cycle time was maintained at 25 minutes.

The ballistic performance of these Spectra shells is shown in Table 9.3.2-1. These Spectra 900 shells had a higher SEAT of 29.2 to 32.5 J·M²/kg compared with the Spectra 1000 shells with a SEAT of 24.5 to 24.9 J·M²/kg.

**Table 9.2.2-1 Ballistic Performance of Spectra 900 and Spectra 1000 Shells
H.P. White Laboratory**

	Spectra Shell No.	Plies	Fabric	Weight in Pounds	V ₅₀	Seat
	G90614-1	26	S/903	2.15	-----	-----
Spectra 900	G90614-3	26	S/903	2.13	2,266	32.5
	G90614-5	26	S/903	2.16	2,162	29.2
	G90614-2	31	S/952	2.51	2,136	24.5
Spectra 1000	G90614-4	31	S/952	2.48	2,140	24.9
	G90614-6	31	S/952	2.52	-----	-----

Nominal cycle: 2 minutes + puncture + 23 minutes, 120°C; 200 tons

Resin: PU/VE 50/50 mixture

The transient deformation of Spectra shells with three (3) resin systems, were measured with .30 caliber fragment simulating projectiles by the U.S. Army and H.P. White Laboratory. The results from the U.S. Army Natick Research, Development and Engineering are summarized in Table 9.2.2-1. It should be mentioned that the Army and H.P. White Laboratory use different techniques to measure transient deformation, which results in minor differences in their data.

The transient deformation of a lighter weight 2.1 pound Spectra shell made with PU/VE resin and a heavier shell, which weighed 2.3 pounds which measured 1.49 inches and 1.50 inches against a .30 caliber, 44 gram FSP at 1,550 fps is shown in Columns E and D, respectively. These results compare favorably with the transient deformation of 1.55 inches measured for a 2.8 pound Kevlar shell at the same impact velocity of 1,550 fps, shown in column H.

Against a 64 grain RCC, the 2.3 pound Spectra shell made with PU/VE resin, Column D, deformed 2.25 inches at an impact velocity of 1,765 fps compared with 2.25 inches for a 2.8 pound Kevlar shell at an impact velocity of 1,752 fps. The difference is marginal and well within experimental error.

Against larger caliber projectiles such as the 64 grain RCC, the transient deformation of a Spectra 900 shell made with PU/VE increased from 2.42 inches to 2.87 inches as the impact velocity was increased from 1,765 fps to 1,919 fps. Also, as expected, the lighter shell of 2.1 pounds deformed more than heavier shell of 2.3 pounds.

9.3 TUMBLE TEST

Tumbling tests of Spectra helmets made with vinylester and PU/VE resins were carried out by the U.S. Army at the Natick Research, Development and Engineering Center over the range of 500 to 1000 tumbling impacts. Spectra helmets with vinylester resin were molded using glass fabric, Kevlar and Spectra fabric as exterior facings. The purpose of the tumbling tests was to screen resin systems and exterior facings (glass fabric, Kevlar and Spectra) to determine the system which would best survive rigorous use by troops. After 1000 impacts, Spectra helmets with vinylester resin using Kevlar as facing, Table 9.3-1 and Figure 9.3-1, showed that more paint was chipped off as compared to helmets with glass fabric, Table 9.3-2 and Figure 9.3-2. When Spectra fabric was used as the outer layer, debonding of rubber edging to the shell was also observed. However, no structural damage was found after the tumbling test. For comparative purposes, Kevlar helmets were also tumbled tested, Figure 9.3. New damaged areas were produced between 500 to 1000 impacts. Sizes and distribution, however, after 1000 impacts were similar to the results of 500 impacts. No debonding of rubber edging was found. Spectra helmets with vinylester resin system appeared to have more paint peeling problem than Kevlar helmets. Spectra helmets, with the PU/VE resin system, were impacted 1000 times, Table 9.3-4. The helmets were examined and found to be free from any structural damage, distortion, delamination or edge debonding. The amount of paint peeling on the Spectra helmets appeared less than for Kevlar helmets. We determined that PU/VE was the most promising resin for this application.

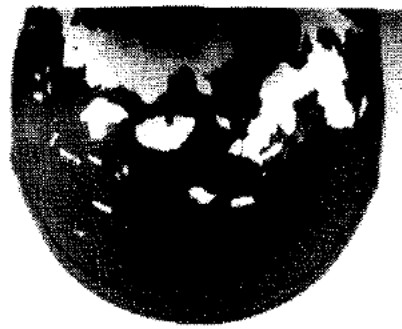
The detailed description of the effect of tumbling on structural and paint damage to Spectra and Kevlar helmets is summarized in Table 9.3-1 and 9.3-2.

Table 9.3-1 Tumble Test Damage, After 500 Impacts

Helmet Samples Damage	# of Impacts	Structural Damage	Paint
1. PASGT Kevlar Standard 3.3 pounds	500	No damage observed	Significant chip of paint around the mid-portion of the helmet was observed. Size of the peeled areas equal (~1 cm dia.) and are evenly distributed.
2. Spectra. helmet VE resin 2.6 pounds 30 layers	500	No damage observed	Same as PASGT but less severe than PASGT. Sizes of the peeled areas are smaller than PASGT.
3. Spectra/Kevlar VE resin 2.75 lbs conventional Kevlar 29, type 913 8 oz/yd ² 30 layers Spectra Kevlar	500	No damage observed	Paint was chipped off very severely. Damage (peeled) areas are evenly distributed. Size of the peeled area is large (< 7 - 10 cm dia.)
4. Spectra/Glass PU/VE resin 2.7 pounds 27 layers	500	No damage observed	Fewer spots of paint peeling.

Table 9.3-2 Tumble Test Damage, After 1000 Impacts

Helmet Samples	Structural Damage	Paint Damage
1. PASGT (Kev/pvb+pm)	No damage observed	Approximately same amount of new damaged areas were produced. Size and distribution were similar to the results for 500 impact. No significant signs of expansion of previously damaged spots.
2. Spectra	Debonding of rubber edging was found	Created approximately same number of new chipped spots.
3. Spectra	No damage observed	Previous spots were expanded largely. Top front and back are almost completely "bald head".
4. Spectra	No damage observed	Producing new spot is minimal. Some localized expansion over previous spots were shown.
5. Spectra PU/VE	No damage observed	Previous spots were slightly expanded.



Spectra/Kev/VE After 500 Impacts

← after 500 impact



Spectra/Kev/VE After 1000 Impacts

← after 1000 impact

Figure 9.3-1 Spectra Helmet With Vinyl Ester Resin and Kevlar Facing



Spectra/Glass/VE After 500 Impacts

← after 500 impact



Spectra/Glass/VE After 1000 Impacts

← after 1000 impact

Figure 9.3-2 Spectra Helmet With Glass Outer Facing

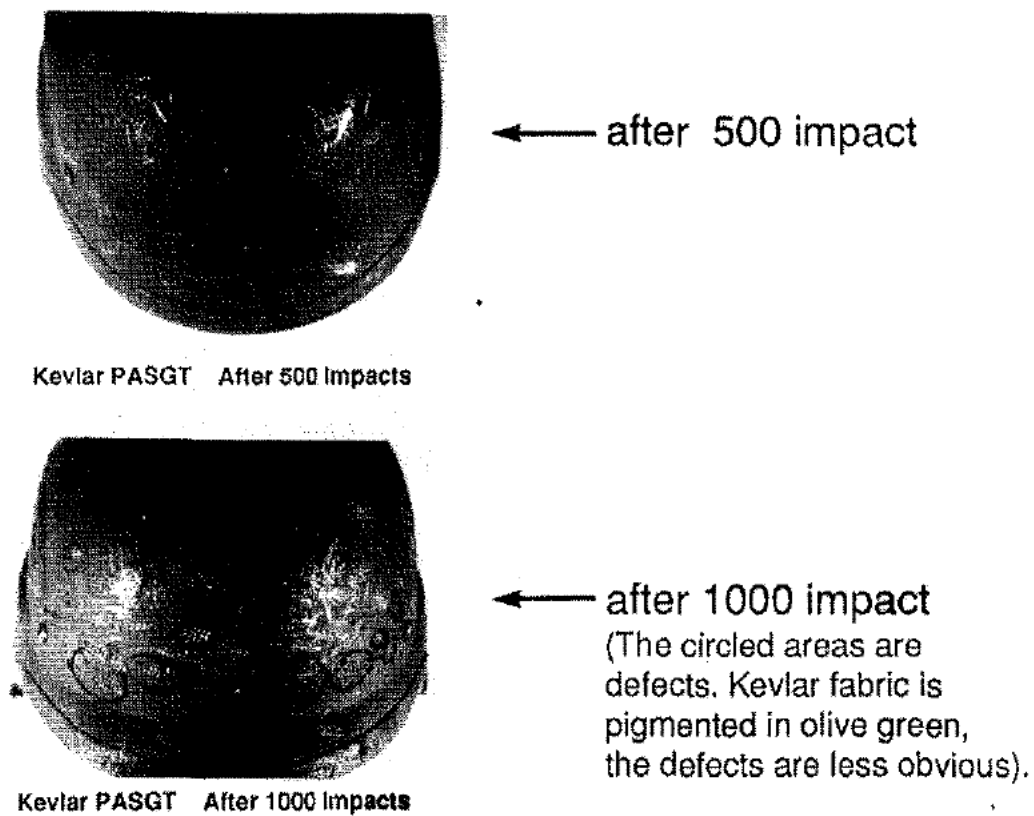
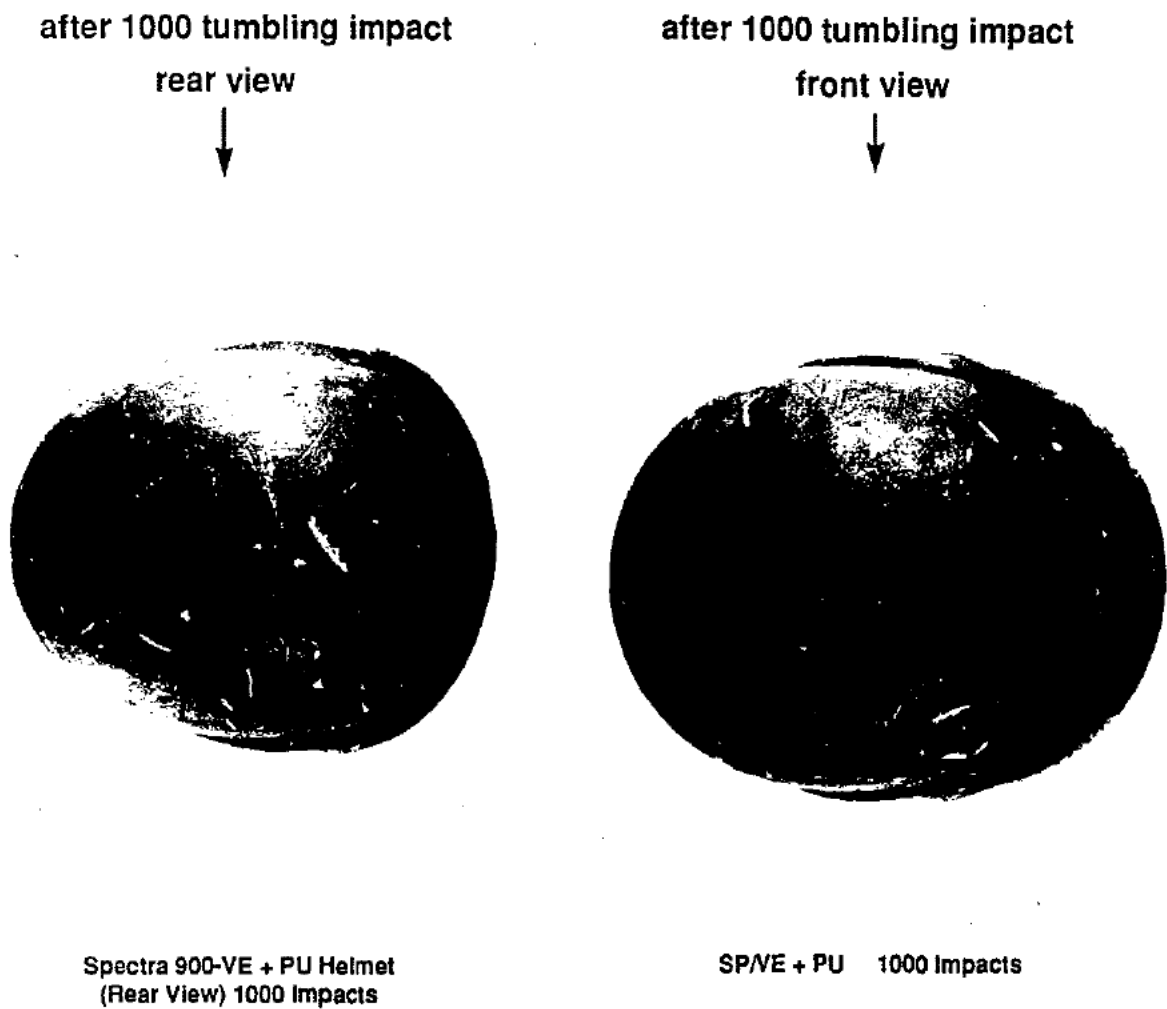


Figure 9.3-3 Kevlar Helmets After 500 and 1,000 Impacts



Spectra Fabric was not pigmented, therefore, minor defects could easily be detected

Figure 9.3-4 Spectra Helmet Made From PU/PE Resin System After Impact Tests

9.4 PEEL TESTING

Our personnel observed that Spectra shells with PU/VE resin delaminated less than shells with either vinylester or phenolic/PVB resin. We determined that a qualitative way to predict the level of delamination was to measure the peel resistance or peel strength of the adhesive resin bonds molded between two flexible Spectra preregs. The standard method for such test is described in ASTM D-1876-72 which is also known as the T-peel test. Two layers of Spectra preregs were molded at a temperature of 120°C for 25 minutes at a pressure of approximately 450 psi. The molded sample was cut into strips 1-inch wide by 6 inches long. The load was applied at a constant speed of 10 inches/minute and the peel strength or force was recorded. Test samples were prepared with three resin system, vinylester, phenolic/PV B, PU (2nd stage coating) and PU (1st stage)/VE (2nd stage). The results of these tests are summarized in Table 9.4-1.

Table 9.4-1 Peel Strength of Spectra Prepreg with Three Resins

Spectra Prepregs with Various Resins	Peel Strength (Pounds/Inch)
Vinylester	1
Phenolic/pv.b	5
PU (2nd stage coating) VE (1st stage coating)	5 - 8
PU (1st stage) VE (2nd stage)	1

From Table 9.4-1, it is important to note that the sequence of the two stage coating of PU/VE significantly affects the peel strength. If PU is coated first on Spectra fabric, and then VE next on the exterior, the peel strength is poor (1 pound/inch). On the other hand, if VE is coated during first stage and PU is next as an exterior coating, the peel strength is significantly improved (5-8 pounds/inch). These results are expected because vinylester is a poor adhesive, while PU is a good adhesive

coating. Thus, PU surfaces will become bonding interfaces, when neighboring layers are molded together as panels.

9.5 BALLISTIC PERFORMANCE RETENTION AFTER ENVIRONMENTAL TESTING

Eight (8) Spectra 900 shells made with vinylester resin, were molded and sent to the H.P. White Laboratory for environmental conditioning and ballistic testing. The results are shown in Table 9.5-1. The SEAT values remained relatively the same for all shells (steam, - 51°C, toluene/isooctane). However, the shell conditioned in hot air at 71°C for 72 hours showed a slight drop of 8.8% in SEAT when compared to the control sample.

Table 9.5-1. Ballistic Performance Retention of Environmentally Conditioned Spectra Shells

V ₅₀ (fps)	Shell* Wt. (Lbs.)	Conditioning	Seat (JM ² Kg)	% Change from Control SEAT	Transient Deformation (17 gr. FSP)	Impact Velocity (fps)
2,130	2.38	Steam 260°F (127°C)	25.7	+2.4	-----	-----
2,150	2.44	30 minutes, 17 psig	25.5	+1.6	19 mm	2,163
2,069	2.39	Hot air	24.1	-4.0	19 mm	2,118
2,035	2.44	72 hours, 160°F (71°C)	22.9	-8.8	20 mm	2,078
2,136	2.38	Freezer	25.8	+2.8	16 mm	2,136
2,116	2.42	72 hours, -60°F (-51°C)	24.9	-0.8	18 mm	2,132
2,079	2.41	Toluene/isooctane 24 hours	24.2	-3.6	17 mm	2,098
2,092	2.35	Control	25.1	ref., 0.0	-----	-----

* With vinylester resin.

SECTION 10.0

PHASE II, TASK B - PRODUCTION OF FABRIC HELMET SHELLS

10.1 FIRST PRODUCTION BATCH, 1989 2.3 POUND SHELL WEIGHT

AlliedSignal Inc. subcontracted with the Sioux Manufacturing Company, Fort Totten, South Dakota to produce 175 Spectra helmets on a standard US PASGT mold, medium size, 0.35 inch wall thickness. These helmets were molded using Spectra style 903, with 31 fabric layers (4 pinwheel, 24 6-lobe and 3 crown patterns). These shells were tested by the U.S. Army and did not meet ballistic requirements in the 2 and 4 grain tests and met the 16 and 64 grain requirement. These shells did meet overall Casualty Reduction analysis requirements. Detailed performance data is shown in Table 10.1-2. The process parameters and equipment used to fabricate these 175 shells are detailed in the following:

Hydraulic press:

PM-350 Ton Clamp, double mold configuration.

PASGT type mold:

Medium size with a wall thickness of 0.35 inch. The mold is ideally designed for Kevlar shells weighing 2.8 pounds. If shells heavier than 3.0 pounds were produced, non-uniformities in wall thickness would result. The ideal weight for Spectra shells in this mold was 2.2 pounds.

Molding conditions:

Mold temperature was 115 degrees C. Mold clamp force was 175 tons. Mold residence time was 23 minutes.

Fabric prepregs:

Spectra 900 fabric (Style 903) with polyurethane/vinylester resin was prepared at Westinghouse in Bedford, Pennsylvania. The resin content was approximately 20% by weight. Details are described in Military Specification MIL-H-44099A, Helmet, Ground Troop and Parachutist.

Preform pattern:

Hand lay-up of preform pattern (c) is shown in Table 10.1-1. The pattern consisted of 8-lobe pinwheels of 20 inch diameter, 6-lobe pattern of 20 inch diameter and ellipse shaped crown patches.

Characterization of Spectra shells and helmets:

Shells with an average weight of 2.3 pounds (36.8 oz) or 25.8 oz/sq. ft. were tested at H. P. White Laboratory and Sioux Manufacturing Company for ballistic performance (V_{50}) in five quadrants against .22 caliber FSP. These results are shown in Table 10.1-2. The results met Natick's specification of 2150 fps minimum.

Thickness of Spectra shell:

Average wall thickness: 0.375 inch.

Max thickness variations: 0.051 inch.

Shell thickness: average maximum thickness - 0.397, minimum -0.347.

**Table 10.1-1 Lay-p of 1989/2.3 lb. Batch
Pattern**

Order	Pattern	Diameter (Inch)	Uncut Center (Inch)	Orientation Angles
1	PW*	20	4.5	0
2	D 4.5•	20	4.5	0
3	PW*	12	4.5	0
4	D 4.5•	20	4.5	20
5	D 4.5•	20	4.5	0
6-10	D 4.5•	20	4.5	40/2/30/40/0
11	Crown▪	8 x 7	4.5	0
12-19	D 4.5•	20	4.5	20/40/0/20/40/0/20/40
20	Crown▪	7 x 6	4.5	0
21-24	D 4.5•	20	4.5	0/20/40/0
25	Crown▪	6 x 5	4.5	0
26-29	D 4.5•	20	4.5	20/40/0/20
30	PW*	12	4.5	0
31	PW*	20	4.5	0

- * 8 - lobes
- 6 - lobes with 4.5inch uncut center
- ellipse shaped with minor and major axis

Table 10.1-2 Ballistic Testing (V₅₀) of Spectra Shells

Spectra Shell No.	Weight Lbs.	V ₅₀ fps (Lot 3)					Tester
		Front	Back	Right	Left	Top	
190	2.27	2,296	2,129	2,091	2,154	2,261	HPW
198	2.27	2,183	2,168	2,203+	2,190	2,181	SM
200	2.30	2,186	2,164	2,200	2,175	2,299	HPW
208	2.31	2,217	2,214+	A*	2,231	2,227	SM
214	2.33	2,159	2,176	2,221	2,188	2,151	HPW
AVERAGE	2.30	2,208	>2,183	>2,179	2,188	2,224	

+ : Partial penetration

*A : No V₅₀

HPW : H. P. White Laboratories, Street, MD

SM : Sioux Mfg. Co., Fort Totten, ND

10.1.1 Spectra 900 Helmets Forwarded to The U.S. Army Natick Research Development and Engineering Center

Table 10.1.1-1 is a listing of the sizes and weights of 40 Spectra helmets forwarded to The U.S. Army Natick Research, Development and Engineering Center August 31, 1989.

Tables 10.1-2 to 10.1-8 are a listing of the detailed shipments of 135 Spectra helmets forwarded to Natick on September 2, 1989.

10.2 SECOND PRODUCTION BATCH, 1990/2.45 POUND SHELL WEIGHT

This batch was also produced at the Sioux Manufacturing Company, Fort Totten, South Dakota using the same mold cavity and a reduced core which resulted in an increased wall thickness of 0.40 inch. This modification increased the helmet shell weight to 2.45 pounds. The number of Style 903 fabric layers were increased to 31 (3 pinwheel, 25 6-lob, and 3 crown patterns). These shells were tested by the Army as were found to be deficient in the 2, 4 and 16 grain fps performance but passed the 64 grain requirement. They also failed the Casualty Reduction Analysis.

Detailed data is shown in Table 10.2-1.

Table 10.2-1 40 Spectra Helmet Shipped to Natick on August 31, 1989

Helmet No.	Weight		Thickness, inches			Max. Variations (High-Low)
	Lb.	Oz.	High	Low	Average	
249	2.29	36.6	.382	.346	.368	.036
199	2.29	36.6	.392	.342	.369	.050
232	2.29	36.6	.381	.348	.368	.033
255	2.29	36.7	.399	.341	.367	.058
204	2.29	36.7	.398	.347	.373	.051
203	2.29	36.7	.391	.349	.373	.042
242	2.29	36.7	.395	.348	.377	.047
193	2.30	36.8	.398	.352	.375	.046
251	2.30	36.8	.390	.341	.374	.049
196	2.30	36.8	.401	.347	.381	.054
231	2.31	36.9	.392	.348	.370	.044
234	2.31	36.9	.387	.350	.373	.037
195	2.31	36.9	.395	.341	.375	.054
225	2.31	36.9	.394	.347	.372	.047
215	2.31	36.9	.403	.352	.375	.051
252	2.31	36.9	.391	.352	.371	.039
238	2.31	37.0	.399	.346	.372	.053
201	2.31	37.0	.400	.342	.373	.058
248	2.31	37.0	.392	.346	.378	.046
217	2.31	37.0	.401	.342	.375	.059
197	2.32	37.1	.390	.341	.372	.049
206	2.32	37.1	.393	.351	.376	.042
205	2.32	37.1	.398	.347	.374	.051
220	2.32	37.1	.405	.347	.378	.058
218	2.32	37.1	.402	.349	.377	.053
244	2.32	37.1	.394	.348	.377	.046
239	2.32	37.1	.399	.342	.372	.057
245	2.33	37.2	.391	.342	.373	.049
211	2.33	37.2	.409	.344	.377	.065
250	2.33	37.2	.397	.348	.377	.049
227	2.33	37.2	.390	.342	.373	.048
262	2.33	37.3	.409	.350	.378	.059
209	2.33	37.3	.405	.350	.379	.055
216	2.33	37.3	.397	.351	.377	.046
253	2.33	37.3	.398	.344	.377	.054
244	2.33	37.3	.398	.348	.377	.050
256	2.33	37.3	.395	.345	.375	.050
219	2.34	37.4	.412	.347	.379	.065

226	2.34	37.4	.410	.347	.380	.063
184	2.34	37.4	.404	.349	.383	.055
228	2.34	37.4	.404	.348	.379	.056
AVG.	2.32	37.0	.397	.347	.375	.051

TABLE 10.2-2 List of 135 Helmets for Natick (Sept. 28, 1989)

Box # 1	18-23-27-30-42-125-129-144-207-295
Box # 2	21-22-24-36-37-47-116-123-183-276
Box # 3	20-31-87-111-137-143-161-222-261-304
Box # 4	52-113-264-266-277-281-284-285-311-318
Box # 5	5-39-106-151-176-235-246-268-272-306
Box # 6	93-132-136-169-174-191-263-291-303-305
Box # 7	4-99-112-145-185-189-296-298-300-320
Box # 8	15-32-134-138-194-221-241-259-269-275
Box # 9	28-45-48-54-55-115-133-142-178-283
Box #10	8-35-46-85-130-146-202-240-288-299
Box #11	40-126-131-140-141-165-286-309-314-316
Box #12	51-107-122-127-135-254-280-287-310-313
Box #13	29-105-109-180-187-273-278-292-290-317
Box #14	77-172-271-274-312

Table 10.2-3 Box #1 (10 Helmets)

Helmet I. D.	Weight (oz.)	Thickness (inch.)		
		Highest	Lowest	Average
18	37.1	.398	.345	.366
23	37.0	.396	.340	.369
27	37.0	.392	.34	.368
30	37.1	.394	.339	.370
42	36.6	.388	.351	.368
125	36.4	.400	.351	.374
129	36.4	.379	.345	.365
144	36.4	.389	.347	.372
207	37.1	.398	.347	.374
295	37.1	.400	.345	.376
Box #2 (10 Helmets)				
21	36.9	.393	.351	.369
22	37.1	.399	.345	.369
24	36.8	.392	.350	.368
36	36.9	.396	.349	.370
37	36.8	.389	.343	.367
47	36.4	.395	.352	.367
116	36.6	.398	.344	.376
123	37.0	.415	.349	.377
183	37.4	.40	.370	.385
276	37.1	.395	.348	.377

TABLE 10.2-4 Box #3 (10 Helmets)

Helmet I. D.	Weight (oz.)	Thickness (inch.)		
		Highest	Lowest	Average
20	36.9	.384	.350	.367
31	37.0	.391	.347	.370
87	36.2	.392	.339	.378
111	36.9	.411	.347	.374
137	36.5	.394	.341	.368
143	36.3	.402	.344	.368
161	37.0	.413	.349	.380
222	36.8	.391	.353	.373
261	36.5	.383	.347	.366
304	36.4	.410	.354	.375
Box #4 (10 Helmets)				
52	36.5	.394	.351	.369
113	36.6	.396	.343	.369
264	36.9	.394	.351	.373
266	37.0	.405	.348	.378
277	37.1	.399	.349	.377
281	37.4	.405	.350	.377
284	36.7	.399	.354	.374
285	37.1	.402	.345	.378
311	37.5	.405	.352	.378
318	37.0	.395	.348	.377

TABLE 10.2-5 Box #5 (10 Helmets)

Helmet I. D.	Weight (oz.)	Thickness (inch.)		
		Highest	Lowest	Average
5	36.8	.390	.353	.369
39	36.8	.405	.346	.370
106	36.4	.400	.349	.373
151	36.2	.388	.344	.366
176	36.1	.403	.346	.377
235	37.0	.395	.348	.372
246	37.1	.397	.348	.377
268	37.0	.398	.352	.375
272	36.5	.386	.349	.371
306	36.8	.393	.351	.376
Box #6 (10 Helmets)				
93	36.8	.403	.347	.357
132	36.7	.396	.341	.373
136	36.1	.383	.340	.366
169	36.5	.399	.350	.373
174	36.5	.403	.347	.379
191	36.8	.399	.350	.371
263	37.0	.397	.348	.370
291	36.3	.392	.350	.378
303	37.0	.403	.352	.375
305	36.9	.395	.342	.375

TABLE 10.2-6 Box #7 (10 Helmets)

Helmet I. D.	Weight (oz.)	Thickness (inch.)		
		Highest	Lowest	Average
4	36.7	.391	.350	.366
99	36.6	.405	.344	.373
112	36.8	.396	.340	.375
145	36.6	.390	.342	.372
185	37.0	.395	.351	.375
189	36.9	.395	.351	.372
296	36.9	.397	.351	.371
298	37.1	.409	.355	.380
300	37.0	.399	.355	.380
320	37.3	.402	.347	.379
Box #8 (10 Helmets)				
15	37.0	.390	.349	.372
32	36.9	.392	.343	.368
134	36.2	.390	.344	.370
138	36.6	.397	.344	.374
194	36.5	.401	.348	.374
221	36.5	.390	.351	.367
241	36.5	.387	.350	.368
259	36.5	.388	.345	.366
269	36.9	.403	.354	.381
275	37.3	.414	.354	.378

TABLE 10.2-7 Box #9 (10 Helmets)

Helmet I. D.	Weight (oz.)	Thickness (inch.)		
		Highest	Lowest	Average
28	36.9	.392	.345	.370
45	36.6	.397	.347	.366
48	36.6	.391	.353	.367
54	36.3	.387	.350	.364
55	36.4	.389	.352	.367
115	36.7	.396	.346	.373
133	36.8	.397	.343	.373
142	36.9	.397	.347	.375
178	37.0	.420	.353	.380
283	36.5	.384	.344	.366
Box #10 (10 Helmets)				
8	36.7	.384	.354	.367
35	36.8	.382	.346	.367
46	36.6	.397	.354	.366
85	36.8	.393	.344	.374
130	36.7	.394	.348	.368
146	36.8	.400	.343	.374
202	36.7	.409	.345	.374
240	36.8	.394	.351	.376
288	37.1	.39	.345	.378
299	37.1	.406	.345	.380

TABLE 10.2-8 Box #11 (10 Helmets)

Helmet I. D.	Weight (oz.)	Thickness (inch.)		
		Highest	Lowest	Average
40	37.1	.385	.348	.370
126	36.3	.387	.341	.367
131	36.7	.397	.345	.370
140	36.9	.407	.343	.379
141	36.9	.400	.343	.374
165	36.5	.402	.348	.372
286	37.1	.407	.348	.373
309	37.6	.407	.352	.373
314	36.8	.395	.347	.370
316	36.7	.397	.352	.374
Box #12 (10 Helmets)				
51	36.9	.408	.352	.373
107	36.7	.396	.347	.373
122	36.7	.392	.340	.370
127	36.2	.386	.346	.365

10.3 THIRD PRODUCTION BATCH, 1991/2.55 POUND SHELL WEIGHT

The third production batch of 40 helmet shells was produced at AlliedSignal's Research and Technology facility in Morristown, New Jersey. For this batch a U.S. PASGT helmet mold with a modified core, 0.4 inch wall, was used. The number of fabric layers was increased to 36, with the 5 outermost layers being Style 904 Spectra fabric coated with vinyl ester resin. During the processing, the mold was slightly overstuffed to produce a thicker helmet shell to avoid the additional expense of further mold machining. This resulted in a mold pillar clearance of 0.10 inch. Crown shims were taped to the core surface to minimize the resulting crown thickness distortions, but this adjustment did leave slight circular depressions on the inside of the helmet shell. The method of fabrication of these forty shells is detailed in Appendix 1. The ballistic performance of these shells is discussed in P. Hudners memo dated March 24, 1992, Appendix 2. The ballistic performance against 2, 16 and 64 grain fragment simulating projectiles met specifications but the 4 grain performance (3,235 fps) was deficient. Dimensional variations existed in these samples, but the wall thickness requirement of 0.35 inch could not be maintained in this 2.55 pounds batch unless a new mold with a thicker wall of .043 inch could be used. This batch did pass the CRA tests detailed in Table 10.3-1. These light weight Spectra 900 helmets were field tested at Fort Wainwright, Alaska by the U.S. Army Cold Regions Test Center from November 18, 1991 through March 2, 1992. The test resulted in findings that there was no difference in the way the Spectra helmets performed from the Kevlar PASGT helmet.

Table 10.3-1 Comparison Between Kevlar, Spectra 1989, Spectra 1990 and Spectra 1992

	Kevlar 1990 Data	Spectra 1989	Spectra	Spectra 1992*
Weight	2.8	2.30	3.45	2.55
Mold Thickness	0.35	0.35	0.40	0.40
Layup				
Pinwheel		2	3	2
D-Pattern		23	25	32 (A,B)
Crown		5	3	2
V50				
17 grain(HP White)	----	2,202	2,250	----
2 grain (BRL)	4,078	3,719	3,750	4,248
4 grain (BRL)	3,464	2,993	3,220	3,235
16 grain (BRL)	2,428	2,447	2,380	2,632
64 grain (BRL)	1,702	1,889	1,950	2,092
Casualty Reduction Analysis				
I	100	98	99	100
II	99	98	98	99
III	100	100	100	100
IV	69	66	67	71
V	95	94	95	97

Date Received: April 28, 1992

Bolded and italicized numbers indicate deficiencies in performance.

* not the proper size mold for a 2.55 pounds shell.

APPENDIX 1

FABRICATION OF FORTY SPECTRA SHELLS

During helmet fabrication, this mold was mounted on a 200 ton (clamp force) press and heated to 119°C using circulating heat transfer fluid.

The molding lay-up used consisted of 36 resin impregnated fabric layers of either Style 904 or 904 Spectra Fabric. The layers were placed in the lay-up container in the following order.

Layer #	
1 (outside surface)	21 inch dia., 6 lobe slit, S904 fabric
2	21 inch dia., 6 lobe slit S904 fabric
3, 4, 5, 6, 7, 8, 9	"B" pattern ply cut from 3 layers S904 plus 4 layers S903
10, 11, 12, 13, 14, 15	"A" pattern ply cut from 6 layers S903
16	14 inch dia. crown layer, S903 style fabric
17, 18, 19, 20, 21, 22	"B" pattern ply cut from 6 layers S903 style fabric
23	14 inch dia. crown layer, S903 style fabric
24, 25, 26, 27, 28, 29	"A" pattern ply cut from 6 layers S903
30, 31, 32, 33, 34, 35	"B" pattern ply cut from 6 layers S903 style fabric
36 (inside surface)	"A" pattern layer cut from 1 layer S903 style fabric

Multiple fabric layer plies included in the above lay-up were first compacted with a press platen heated to 70°C, a pressure of 120 tons/ft², and a duration of 5 minutes. Six lobe "A" or "B" patterns were later cut from these 21x21 inch compacted plies.

All fabric in the lay-up "S904" consisted of Style 904 Spectra fabric, corona surface treated, vinylester resin impregnated to a 19% content. All fabric labeled "S903" consisted of Style 903 Spectra fabric coated with an equal mixture of Derakane 8084 vinylester and polyurethane yielding a final resin weight content of 16%.

The molding lay-up, which weighed approximately 1700 grams, of coated fabric was placed on the core section of the mold and pressed with a 200 ton clamp force for three minutes. The press was opened and the helmet shell was punctured six times in the area of the inside crown. Style 903 Spectra fabric crown shims were taped on the core section and covered with a release film barrier. The crown shims consisted of two circles of 4 inch diameter and fiber circles of 7 inch diameter. The mold was closed under a 200 ton clamp force for an additional twenty minutes. The mold was then opened and the finished shell was removed.